

A FIELD GUIDE TO

Clean Drinking Water

How to Find, Assess, Treat, and Store It



**FOR TRAVELING • TREKKING
OFF-THE-GRID LIVING • WATER EMERGENCIES
WHENEVER YOU CAN'T TAKE IT FOR GRANTED**

JOE VOGEL

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A FIELD GUIDE TO CLEAN DRINKING WATER: *How to Find, Assess, Treat, and Store It*

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Translated by Carolin Sommer



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Preface

Unless you go on extreme travel adventures or take part in expeditions in the developing world, you wouldn't normally worry about water or where it comes from. And why should you?

The most important ingredient of life for all creatures on Earth has become a means not only for washing, bathing, or flushing toilets, but also as a cooling agent during energy production and to form the basis of steel and paper manufacturing. In the form of rivers, it serves as a means of transportation and as a dumping ground for industrial waste, toxins, and sewage.

In some areas where drinking water is in short supply, large companies pump water from the ground and sell it in bottled form back to a suffering population who can no longer use their own wells due to the subsequent drop in the water table. (It is these sealed bottles, by the way, that tourists rely on as a seemingly safe source of drinking water.)

And yet, apart from clean air, drinking water is the most important ingredient for life—no wonder access to water is considered to be a human right, given that we need clean water and air just as much as we need solid food.

When I say “drinking water,” the image that likely comes to mind is the glass of water that comes courtesy of your tap, but when talking about drinking water from a global perspective, I also include in that water from almost all lakes and streams in remote areas in North America. Compared to the water quality of the rivers of Asia, Africa, South America, and Russia, water from these sources can be considered drinking water rather than ordinary river water or even wastewater.

My personal philosophy is: If it's clean enough to swim in, it's clean enough to drink.

However, that hasn't always been the case. For most of the twentieth century, the Potomac River, for example, was a dangerously contaminated, filthy soup, highly polluted with heavy metals, chemicals, and raw sewage, all of which were released almost entirely untreated into the water.

Since the introduction of the 1972 Clean Water Act, the quality of surface waters in the USA has improved significantly. Today we have a situation in the West where the continuous improvement of sanitation networks has gone hand in hand with what appears to be a practically guaranteed supply of clean water. Should that supply actually fail for a longer period of time, we have enough drinking water in our natural surface reservoirs, such as the Great Lakes, to last for decades.

Nonetheless, it remains to be seen how much the water situation in North America will be affected over the next few decades by climate change (which is undeniably happening). Even a small rise in sea levels can have a substantial impact on groundwater salinity. Failing rains or abnormal spring floods can affect the availability of **raw water**: Sanitation networks depend on average rainfall; too little rain can have a detrimental effect on waste removal and cleaning of the sewage pipes as well as reducing the availability of raw water. On the other hand, too much precipitation can contaminate surface waters and put a strain on the sewage network. North America is already regularly affected, and by all accounts increasingly so, by natural disasters that have a detrimental

effect on the water supply.



After days of dwindling water reserves in a semidesert, water reserves can at last be topped up again—and the first opportunity of a shower in over a week.



Life is only sustainable
where there is water.

Unfortunately, human physiology is not at all designed for barren spells. And so, from the very first beginnings, humans have always settled near water. It wasn't by chance that the first advanced civilizations developed by the Tigris and the Euphrates, the Nile, and the large inland lakes. Humans have always needed one thing above all as a means of transportation and a source of food: water—reliably, and on a daily basis. The loss of a water supply has been the downfall of entire civilizations—for example, when the distributaries in the Nile Delta silted up, cities were deserted, and entire peoples went on the move.

Throughout our developmental history, humans never had to go without a constant water supply for any periods of evolutionary consequence. This explains why, compared to other animals, the human metabolism is downright wasteful with its stored fluids. This manifests itself in our daily water requirements and in the swiftness with which death occurs when we're without water.

At moderate temperatures and normal activity levels, humans need between two and three liters of water a day. With increased temperature and activity, however, this requirement soon rises. For example, while acclimating in hot areas and with high activity levels, I drink between five and eight liters daily for several days. If under such conditions our body's need for water increases due to illness, our supply of water is lost due to leakage, or our reserves run low, the situation can quickly turn dangerous.

Usually, the reasons are trivial. Sometimes the pressure of a whole nation using air conditioning in the summer can lead to power outages that prevent water towers from being replenished. An average flood might be all that is needed to distribute leaked effluent not only over fields but also into surface waters that serve as reservoirs. After a few days, the risk of an epidemic becomes high. We have seen several such cases in recent years—for instance, in the US in Puerto Rico after Hurricane Maria in September and October of 2017, or in Europe with the great southeast European floods in May 2014.

Individual and extreme travelers or even those on package tours put themselves in additional danger. Due to their crumbling or only recently established infrastructure, developing countries, and that includes many popular holiday destinations, are often unable to restore the supply of drinking water in unforeseen circumstances. This is a risk even in so-called “developed” countries (as illustrated by “the most powerful nation on Earth” in August 2005, when Hurricane Katrina led to an acute failure of emergency services and the military’s inability to support its civilian population).

Many ordinary trekkers came to realize this in 2015 when they were alerted with a literal jolt to the importance of improvised water **treatment** when the water supply of one of the world’s great hiking destinations was effectively thrown back to a preindustrial state. In April that year, a massive earthquake shook the remote country of Nepal in the southern Himalayas—in peak tourist season. With an epicenter located not far from the capital, Kathmandu, the quake was followed by several powerful aftershocks.

The 2015 Nepal earthquake highlights the importance of improvised water supplies for travelers. Given that it contained virtually all the relevant factors of a water emergency, we will briefly analyze the situation in more detail here.

When the quake struck, in addition to the expeditions exploring the foothills of Mount Everest, there were also thousands of backpackers in Nepal’s towns and cities, with many hundreds more trekking through the extensive tourist



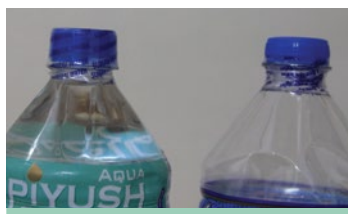
Thamel, Kathmandu's tourist center, in 2017: Two years after the earthquake, countless water pipes remain unrepaired. Popular travel destinations can become crisis regions fast.

regions around the Annapurna massif and other remote areas. These travelers (many of whom were carrying a copy of this book) were just as affected by the subsequent disaster as the local population.

Nearly nine thousand people perished and a hundred thousand buildings were destroyed. The country's infrastructure, barely functional at the best of times, had collapsed as well. In many areas, the canalization (where it existed) had caved in, water pipes had burst, and suddenly not just thousands of Europeans but an entire city of a million people was left high and dry. Within a short amount of time, all the bottled water, so popular with tourists, was sold out. At twenty-five cents per liter, these bottles were out of reach for most Nepalese people, but for most trekking travelers they were the last line of defense. Very few of them had brought a water filter or something similar and instead had relied on the supply of bottled water. Hindered by the damage caused to the already awful and largely unsurfaced roads of the country, it was almost impossible to haul sufficient drinking water to towns and cities in the aftermath of the quake. And so, wildly colored Indian trucks crawled up the steep mountain serpentines in order to ease the worst of the need. This water, however, was not always suitable for Western stomachs (more on this in Chapter 4). Given the circumstances, not all the water came from clean mountain rivers.

The country's bottleneck was its tiny airport, used by virtually all the tourists leaving and all the aid organizations arriving there. It took days, in some cases weeks, until all the tourists were able to make their way to the capital's airport

Backpackers' favorite "sealed bottles": Seals like these are easy to produce by anyone—and can easily rip off an unsuspecting tourist



and be flown out, often after having contracted diarrhea and other infections first.

The situation was made even more problematic by the fact that due to the large number of wounded in the quake, antibiotics that could have been used to treat these infections had nearly run out. It was only thanks to coordinated action by aid organizations, and rain, that the outbreak of a large-scale epidemic was averted.

Why did the water situation get so out of hand? After all, Nepal is a markedly water-rich country with thousands of rivers fed by the glaciers from its countless peaks.

Kathmandu is situated on the river Bagmati (or Kareh), which carries enough water for any emergency situation. The river springs, crystal-clear, in the Himalayas, but even before it reaches the outer limits of the city, it has turned into a foul-smelling sludge. The problem is twofold: Local (small-scale) industry dumps waste into the river, and thousands of open sewers that collect the waste spewed by the giant city into its environment also empty into the Bagmati. This river of effluent then discharges into nothing less than the Ganges, a river millions of people depend on for their daily drinking water.

In the spring of 2017, I was able to see the prevailing water situation in Nepal for myself. Most of the rubble had been cleared by then, but in the old town burst water and sewage mains were still being repaired, with their contents seeping into the ground only to resurface in a different place. Untreated effluent was still being discharged straight into the rivers—in other words, into the drinking-water reservoirs. Remote parts of the country were still being supplied by water tankers. The rural population depended on public standpipes, and the number of tourists was on the rise again. *Many of them had never concerned themselves with drinking-water purification and still relied on bottled water.*

These examples aside, there are many other reasons why an understanding of this vital ingredient of life, which normally spurts reliably from our domestic taps, can be essential for survival even today.

I am sure we can agree on the fact that the expertise to locate drinking water in the environment, assess its quality, and treat it accordingly can be just as important as the skills to make fire or source food. We need to reacquaint ourselves with these techniques and skills that we have neglected while enjoying the luxuries of modern life.

Only equipped with the correct knowledge can we recognize the limits of human physiology in an emergency, our own abilities and what is feasible in a given situation in order to make the right decisions when preparing for a trip or dealing

with a crisis.

I started working on this book over ten years ago when no literature on the subject was available for travelers, day hikers,

Many people around the world cannot afford bottled water and depend on public watering places. Travelers should not rely on bottled water for their needs.



Where there is effective sanitation, there will be usable water during an emergency. This slop is worse than useless.



survivalists, outdoor enthusiasts, or backcountry campers. Since then I have published a number of books about plant- and animal-based survival food, outdoor and survival medicine, and general wilderness skills. A field guide to drinking water has long been overdue.

I hope that you, dear reader, will enjoy getting your teeth into the “invisible foes” of life and survival with the usual curiosity and love of experimentation—even if the results won’t always be immediately tangible.

The skills I’m imparting in this book may simplify, or even save, your life—whether in an emergency or any situation where clean drinking water may not be readily available.

I hope you will enjoy reading this book and practicing your new skills, and above all I wish you much success with their implementation.

—Joe Vogel

Notes:

1. Where measures are given in liters, one liter is roughly equal to one quart, one quart is equal to thirty-two fluid ounces, and four quarts equal to one gallon.
2. Terms in **boldface** are defined in the glossary at the end of the book.

Clean Drinking Water: The Big Picture

For many of us, the privilege of having access to clean drinking water is something we hardly think about, if at all. Yet the data made available by the World Health Organization is as plain as it is disturbing. Despite the enormous progress made in the past twenty years, the poorest people on our planet are still being denied access to safe drinking water. Especially in the conflict areas in sub-Saharan Africa as well as in those young democracies that were established in the former colonies after decades of civil war, access to clean water is often a privilege reserved for the wealthy elite.

Even today, more than seven hundred million people have to make do with water collected from channels, ditches, and rivers, and often without the means for making it safe. But still, twenty years ago the number was three times as high. At the same time, around a billion people still don't have adequate sanitation but instead discharge fecal matter and other effluent untreated into the environment.

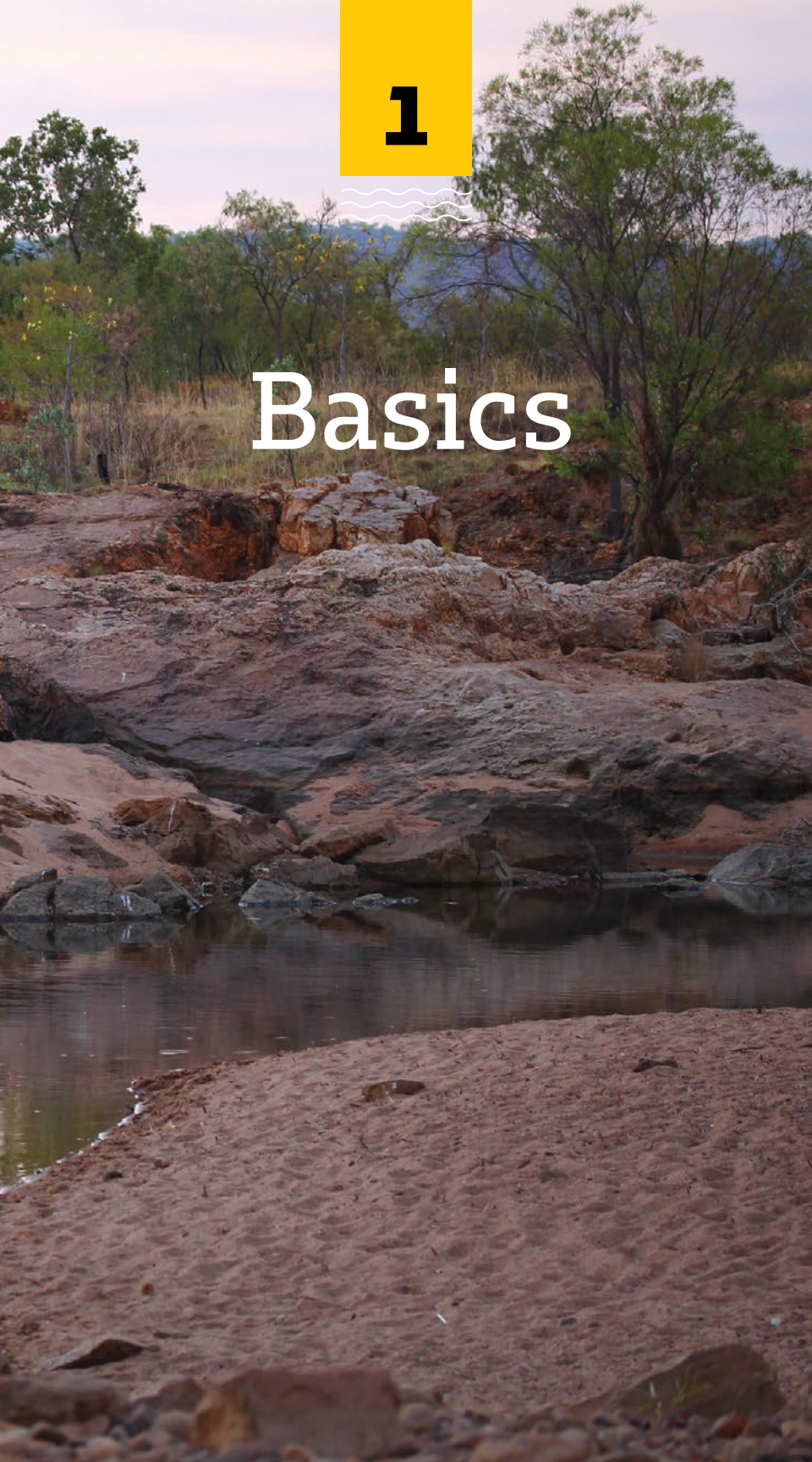
Rural areas in particular see high instances of contaminated **raw water** coinciding with the absence of a clean water supply. It comes as no surprise that this vicious cycle of infection and recontamination of the environment makes the occurrence of epidemics more likely. In the living environment of the billion people without sanitation, it is but a short step to disaster when immature water treatment facilities collapse and the people return to collecting untreated surface water.

Depending on the data source consulted, every year **waterborne diseases** kill between two and five million people across the globe. A significantly larger number fall seriously ill and become unable to work or suffer from ill health for the rest of their lives.

With the public's mind largely focused on world hunger, access to clean drinking water and especially to sanitation is usually sidelined. And yet, next to hunger they are the two main global health factors, especially as regards infant mortality, and therefore, paradoxically, mutually responsible for overpopulation in rural areas in developing countries. (The higher the infant mortality rate, the more children are born and raised.) This means that the absence of access to water and sanitation have explosive political power.

This selective public focus is also the reason why the subject of drinking water is one that is often ignored until it is too late. In contrast to food, for which we have several giant "storage depots" in our body, we mammals almost need to be permanently connected to a water pipe. Just like with an internet connection, which only enters our awareness when it happens to be interrupted, the constant availability of clean drinking water means that we neglect this important resource almost entirely until we're in a desperate situation, or, as you might be, planning on taking a trip to a place where drinking water can no longer be taken for granted.



A landscape photograph showing a rocky riverbank. In the foreground, there is a sandy, reddish-brown bank. The middle ground features a calm body of water reflecting the sky and surrounding vegetation. The background is filled with lush green trees and shrubs under a soft, hazy sky. A yellow rectangular graphic with the number '1' and white wavy lines is positioned in the upper left corner.

1

Basics

Basics

The human body is roughly 60 percent water, so it's no wonder that water plays a prominent functional role in our bodies. Before we dive into how to find, assess, and treat water, it's important that we first understand the basics: how water is processed in the body, what dehydration actually is, how to calculate our individual water requirement for any type of excursion (and plan accordingly), and how to safely ration and store water during or in preparation for any kind of water emergency. That's what we'll cover in this chapter.

Water and its role

In the body, water plays an important role in the transportation of a host of different substances within the blood and lymphatic systems. Blood—a cell/water suspension—carries sugar, antibodies, hormones, fats, proteins, oxygen, and much more around the body. For the blood to be able to fulfill this role and transport these substances into the remotest regions of the body, it requires a certain **fluidity**. When a lack of water causes blood to become too “viscous,” there is a risk of serious circulatory disorders and organ damage.

In addition to the obviously liquid blood, all the other cells in the body also consist mainly of water. Any ingested liquid finds its way into the blood via the stomach and gut; pressure from the heart and **osmosis** subsequently force it into every individual body cell as cell water (see “Reverse osmosis,” page 175) and in between the cells as lymph.

This means that every living part of the body is constantly bathed by “water,” with ten times more “cell water” than “blood water.”

To distribute available liquid into blood and for intracellular fluid to work, the body needs many **minerals** and salts, which are ingested partly through drinking water but to a larger extent through food. The body regulates its precise water-mineral balance hormonally.

Water also plays a vital part when exiting the body. Following is a simplified overview of water-related processes in the body as well as countermeasures against dehydration and water poisoning.

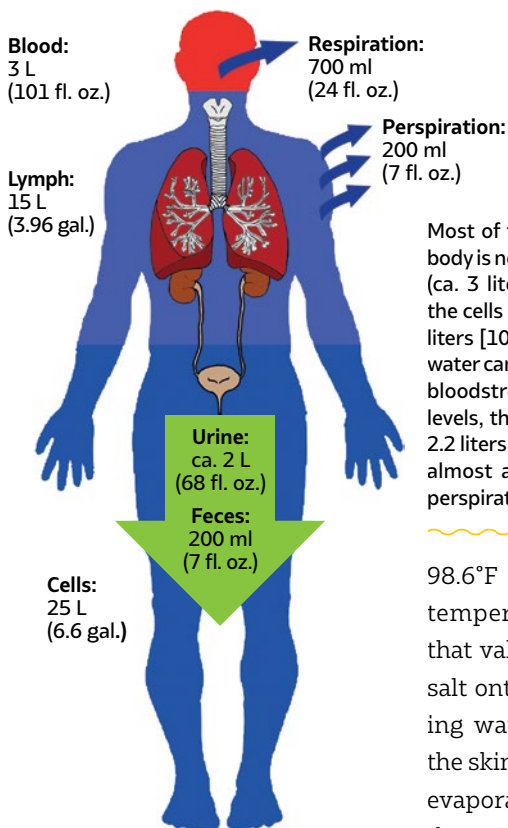
Water's purpose in the body

When there is excess water in the blood in relation to body mass and electrolytes, large amounts will be removed by the kidneys as urine. The same applies when certain waste products, toxins, and minerals have accumulated in the blood. Such substances (creatinine, excess salt [sodium chloride], urea, small amounts of uric acid, etc.) need to be removed from the body by the kidneys or they will lead to symptoms of serious poisoning. At worst they can lead to a potentially fatal “osmotic diuresis,” where kidney function, and therefore all other organ function, is inhibited.

The body's priority in regulating the internal fluid cycle in a water-deficient situation is to retain liquid. Drinking too little water can, therefore, lead to an accumulation of minerals and toxins in the body; these are passed with urine as soon as sufficient liquid is taken in again. When there is sufficient water in the blood, the kidneys will excrete urine with a high water content and low concentration of minerals. The more a person drinks, the sooner they will have to “pass water” again.

With insufficient water in the blood, however, the excreted urine is more concentrated, a “thicker” urine with little water. As this only works up to a certain osmotic concentration (or **osmolarity**; see “Sodium chloride [table salt],” page 107), the body relies on replenishment with fresh water to resolve the situation. It has no effective means of compensating for a lack of water.

Another vital function is perspiration. All processes within the human body are adapted to an optimal temperature around



Most of the water in the human body is not contained in the blood (ca. 3 liters), but in and around the cells in various tissues (ca. 40 liters [10.6 gallons]). From there, water can be carried back into the bloodstream. At normal activity levels, the body excretes around 2.2 liters of water a day and loses almost another 1 liter through perspiration and respiration.

98.6°F (37°C). When body temperature rises above that value, the skin carries salt onto its surface, drawing water to follow it. On the skin's surface, the water evaporates and thus cools the system. As the salt does

not evaporate but continues to “draw water,” the body usually loses more water than salt. High ambient temperatures as well as exercise increase a person's water requirement.

Since most of the body's water is usually lost due to excretion (the production of urine), the body's fluid balance is effectively maintained by managing the amount and the concentration of the urine. This is done with the help of the antidiuretic hormone (ADH), also known as vasopressin, which also plays an important role in dehydration.

What you should know is that in a water-deficient situation, the release of ADH counteracts any further loss of water. The consumption of diuretic foods and drinks, however, can negatively impact the effect of the hormone. Above all, even small amounts of alcohol will greatly reduce the amount of ADH released, which is why you must never consume alcoholic drinks when you are already dehydrated!

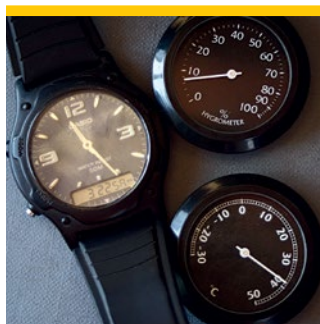
From dehydration to exsiccosis

Dehydration ends in **exsiccosis**, a drying out on the inside. There are several stages in the process, each of which can be fatal depending on the circumstances. Water deficiency in a very hot environment, for example, can lead to heatstroke or overheating of the internal organs when the sweat glands can no longer transport water to the surface of the skin. Furthermore, dehydration due to water deficiency is the same process as the one that leads to terminal dehydration after severe and sustained diarrhea (such as with cholera or dysentery).

In principle, dehydration begins with the most recent consumption of drinking water. As the fluid balance is still maintained, there is no reason for the body to store liquid for drier times. The body begins immediately after the ingestion of water to channel extra water via the kidneys toward the bladder. The more water is available for the production of urine, the less energy is needed to concentrate the urine, and the more effectively any waste products can be excreted. At the same time, delivery of water to the saliva, sweat, and tear glands carries on as normal. In this state, there is sufficient water for all important bodily functions.

Depending on the level of perspiration, however, the body soon realizes that there is no more excess water available.

In the Libyan desert just before noon: nearly 104°F (40°C) in the shade with less than 10 percent relative humidity. That means one thing only: Rest and wait for the cooler evening hours.



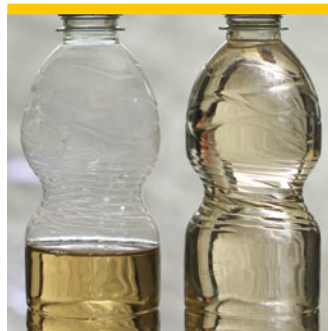
The production of urine created a temporary “ideal state,” which only lasts for a very short period of time. The body notices a decrease in the amount of blood and immediately releases ADH. The hormone has several effects: an increased concentration of urine in the kidneys and narrowing of the blood vessels. The decreasing blood level and the increasing sodium concentration in the blood signal “thirst!” The mouth goes dry.

Physiological processes during dehydration

Normal	Symptoms
– “Wastefulness phase” – Sufficient water in the body: reduced levels of ADH – Expanded vessels – Intensified secretion (increased production of sweat, saliva, etc.) – Reduced water reabsorption in the kidneys Balanced secretion (normal production of sweat, saliva, etc.)	Usually only after overconsumption of liquids: Excessive urine excretion; in rare cases spasms, nausea, headaches and reduced consciousness due to lowered sodium levels (hyponatremia)
Deficiency	Symptoms
– “Preservation phase” (no ill effect on health) – Slightly too little water in the body: slightly increased levels of ADH – Slightly narrowed vessels – Balanced secretion (normal production of sweat, saliva, etc.) – Intensified water reabsorption in the kidneys Reduced secretion (severe reduction in production of sweat, saliva, etc.)	Slightly smaller excretion quantities than normal. Dry lips and mouth. An increasing, but still manageable, thirst for water.
Crisis	Symptoms
– “Survival phase” (critical situation) – Insufficient water in the body: significantly increased levels of ADH – Fast loss of water through nonconcentrated urine, heavy loss of minerals – Considerable reduction of water loss through concentrated urine Minimal excretion of heavily concentrated urine	Pain in the upper right stomach. Painful anuria, only passing some dark red droplets of urine. If you pinch the skin on the back of the hand, it stays elevated in position. Heavy headaches, loss of consciousness, multi-organ failure.

The lack of water first causes a reduction in readily available blood water; lymph slowly drains into the circulatory system and compensates for the water loss. Without a corresponding narrowing of the vessels, the body would suffer an immediate shock.

The amount of urine excreted in the harmless preservation phase (left) is significantly lower than in the balanced wastefulness phase.



Urine reduces in volume and gets darker in color until only a few red drops are passed. The concentration of water-soluble urea is limited. In contrast to birds and reptiles, which can excrete pure uric acid, humans need enough water to pass urea. At the same time, the level of osmotically bound water in the blood gradually rises as the reduced amount of urine doesn't flush enough salts out of the body.

Over time, the glands stop producing any secretions at all. The mucous membranes and the eyes begin to dry out, and the body is no longer able to produce sweat to cool down. At this point, you may well die because of heatstroke or organ failure.

In this state, the imbalance in homeostasis and the nonexcreted salts and toxins (and thus the potential for increased sodium level) may lead to bad cramps, cardiac arrhythmias, severe headaches, and cerebral **edema**, as well as episodes of aggressiveness. You become less and less responsive. Water levels in the cells decline, and the skin loses its tone. Skin pinched on the back of the hand no longer returns to normal.

In addition, there is pain in the kidneys, and later in the entire abdomen. The low fluidity of the blood leads to insufficient circulation in the extremities. You can no longer stand up without collapsing nor speak coherently. Reduced blood pressure causes acute kidney failure. Clots form in the fine vessels of many organs and in the brain capillaries, followed by delirium, multiple organ failure, and eventually death.

Depending on temperature, sun exposure, and activity, the time between a person's last sip of water and death can vary between several hours and over a week. Depending on the severity of the dehydration, one countermeasure is to give spoonfuls of clean drinking water. If the patient is no longer willing or able to take in water, their only real chance of survival is infusion, to be administered by medical professionals. Depending on the type of dehydration, infusing the wrong kind of liquid can lead to fatal complications.

Hyperhydration—water poisoning

Hyperhydration is a risk that is usually estimated to be much greater than it actually is. It is true that drinking large

amounts of water can lead to a drop in salt and mineral levels in the body when combined with heavy perspiration and urine production. An important factor is the falling sodium level in the blood, which plays a vital role in bodily functions. Hyperhydration can occur, for example, during acclimatization in hot regions when taking in relatively large amounts of water but not much food because of the heat.

Long-distance runners and jungle hikers, too, are familiar with the phenomenon. Since minerals are mainly absorbed from food and rarely from beverages, it is irrelevant if the drink is isotonic sugar water from a can, pure drinking water, or freshly distilled water. As long as you ensure that in hot regions and with increased activity levels you take in a little food (slightly salty if possible) and don't drink inordinate amounts, the risk of water poisoning is low.

The consequences of hyperhydration, however, are no less dangerous than those of dehydration: cramps, vomiting, headaches, edema—and potentially death.

For a person to contract water poisoning while following a normal diet, they would have to drink literally many liters of distilled water after several days' fasting. The number of people who have died from hyperhydration is negligible compared to those who have died from exsiccosis due to illness or water deficiency.

Water in emergencies— and while traveling

The question of whether water will have to be obtained from the environment and purified is not just one for emergencies or catastrophes, but also one for every simple backpacking trip of more than one day.

Our problem as a species is that we are generally quite wasteful with our water reserves. And I don't mean the mantras of "Shower, don't bathe" or "Don't run the tap while brushing your teeth" (which, incidentally, in water-rich areas such as most of the central and eastern states of the US is not only unnecessary but also counterproductive from a sewage

disposal point of view). Instead, I am talking about the use of water by the human body. It is often claimed that the most important water transportation device is your own body. And of course, if you are experiencing water deficiency, you should compensate for the loss of water as soon as possible when you reach a safe source. But faced with the choice between entrusting my body with one liter of water or taking it with me in a bottle, I will opt for the bottle every time. True, we have to drink at regular intervals, but our body doesn't store or ration the ingested water but rather immediately squanders it like a schoolboy who finds himself with some unexpected pocket money. This innate hedonism in our fluid regulation means we have to ration our water supply as described in more detail in this chapter.

To estimate the necessary amount of water, we start by looking at a person's normal water requirement. Note that in this calculation we don't include the amount of water needed for cleaning teeth, boiling pasta, or washing feet, but purely the amount of drinking water that our body needs, whether freely accessible or contained in wet foods and drinks.

Water requirement

To give a blanket figure for a person's water requirement is obviously not possible. Every organism apportions its water reserves slightly differently. Besides, external circumstances strongly influence the body's needs. Activity, age, gender, acclimatization, temperature, altitude, and humidity all play a role.

The rule of thumb given below is to be taken as a point of reference to help you estimate the amount of drinking water needed. You can use it to roughly calculate the amount of water you will need for any kind of expedition or independent travel.

Formula for the calculation of the daily water requirement

$$\text{Basic amount} + \text{Activity amount} + \text{Temperature amount} + \text{Altitude amount} = \text{daily water requirement}$$



The required amount of drinking water varies enormously. A person weighing 175 pounds (80 kg) may need anything from 1.5 liters to more than 6 liters (1.6 gallons) when training competitively in the mountains during the summer. Such quantities are hardly portable.

Basic amount (normal water loss through respiration, skin, excretion)

under 110 pounds [50 kg] body weight: **ca. 1.5 L** [51 fl. oz.]

110–175 pounds [50–80 kg] body weight: **ca. 2 L** [68 fl. oz.]

176–220 pounds [80–100 kg] body weight: **2.5 L** [85 fl. oz.]

over 220 pounds [100 kg] body weight: **3 L** [101 fl. oz.]

Activity amount*

(based on the main activity carried out over the day)

low (resting, camping): **0 L** [0 fl. oz.]

medium (easy hiking, paddling): **basic amount ÷ 5**

very high (mountaineering, snowshoeing): **basic amount ÷ 3**

Temperature amount

(based on the average temperature over the course of a day)

below 68°F [20°C]: **0 L** [0 fl. oz.]

68–95°F [20–35°C]: **basic amount ÷ 5**

over 95°F [35°C]: **basic amount ÷ 2** (and more)

Altitude amount†

(rule of thumb for altitudes over 3,300 feet above sea level)

for each additional 3,300 feet [1,000 meters]: **basic amount ÷ 3**

* The activity amount is adjusted to a sustained level of activity over several consecutive days. During high-power workouts or when running a marathon, you will need several (incalculable) times the activity amount given here. Obviously, the guidelines here do not make allowances for such intense activities.

† With increased altitude, the water requirement increases because of a higher breathing rate and reduced organ activity.

Model calculation for moderate consumption

Body weight: 165 pounds [75 kg]		2 L [68 fl. oz.]
		+
Activity level: medium (mountain biking)	2 L [68 fl. oz.] ÷ 5 =	0.4 L [14 fl. oz.]
		+
Temperature: 77°F [25°C]	2 L [68 fl. oz.] ÷ 5 =	0.4 L [14 fl. oz.]
		+
Altitude: 2,500 feet above sea level		0 L [0 fl. oz.]
		=
Drinking water requirement :		ca. 2.8 L [96 fl. oz.]

Model calculation for high consumption

Body weight: 190 pounds [87 kg]		2.5 L [85 fl. oz.]
		+
Activity level: very high (mountaineering, 6–8 hours per day)	2.5 L [85 fl. oz.] ÷ 3 =	0.8 L [28 fl. oz.]
		+
Temperature: below 68°F [20°C]		0 L [0 fl. oz.]
		+
Altitude: 13,000 feet above sea level	4 x (2.5 L ÷ 3) =	3.3 L [113 fl. oz. / 0.9 gal] (!)
		=
Drinking water requirement :		ca. 6.6 L [226 fl. oz. / 1.77 gal]

At first glance, these calculations seem complicated, but they are very helpful when estimating the water requirements for a trip. The calculated amount is also a good benchmark for maintaining fluid balance. When traveling at high altitudes, for example, fluid balance is per se negative as it is virtually impossible to drink as much as would be necessary.

The two example calculations allow us to determine the amount of water we need to carry with us. In the moderate-consumption example, we would need around 3 liters per day. For a four-day trip, we would therefore need to carry—or collect—12 liters (3.2 gallons).

In the case of very high consumption, however, the situation looks very different. With a daily requirement of just over 6.5 liters (1.8 gallons), we are looking at 26 liters (nearly 7 gallons) of water to maintain fluid balance on a four-day trip. For a few days, this amount is actually portable, but not on one's back. Ideally it would be pulled in a transport cart. This becomes a necessity especially where the environment is not conducive to sourcing water en route, such as gravel and sand deserts.

For certain extreme trips, the best option is to set up water reserves along the way (as done by trekkers in better developed deserts such as the Negev in Israel). If, however, you are traveling in regions where it is impossible to set up water reserves by vehicle, or too expensive to drop off such reserves by helicopter for an expedition, the only option is to take as much water as possible with you and to ration it from the start by only drinking half of what is actually needed. This means you will technically find yourself in a state of long-term dehydration, but which—with reduced performance—is tolerable for a few weeks.

The decision on how much water to carry can be a dangerous balancing act, especially if you're only using a backpack, not a cart. With every additional liter of water you are adding another kilogram (two pounds) of weight to your back. If you think you want to be extra well-prepared for the aforementioned four-day trip and take, say, 10 liters (2.6 gallons) more than the usual or adapted weight of your backpack, the resulting heavy perspiration will increase your need for water quickly. Yet, in areas of water shortage, heavy sweating should always be avoided—which is why only inexperienced desert travelers hike at midday (when it's hot)—or even wearing black clothing.

Not only does the activity amount increase, but when you have a break because you're exhausted, you also feel thirstier



Forty liters (ten gallons) of treated drinking water: In the blazing hot regions of western Australia, this amount won't last a single week.

and tempted to drain a whole bottle of water (thinking “I’ve got plenty!”). It is, therefore, quite possible that you will effectively have less water

available than if you had brought 10 liters (2.6 gallons) less.

Almost always, more weight means more breaks, and therefore the daily distance that can be covered will be less. If you need to reach the next water station or civilization, an extra one or two days’ march means an extra water demand for 5 to 10 liters (1.3 to 2.6 gallons). Because of the high **density** of water, the ideal solution is therefore to collect and treat water on the way.

Water on trekking tours

Most people on simple trekking tours will be constantly confronted with the search for clean drinking water, and this is where most uncertainties seem to arise: Some talk about getting water from clean rivers, which, despite being filtered, led to severe infections. Others circulate recommendations on how much water should be drunk per mile, or even advise carrying the whole required amount of drinking water from the start instead.

In fact, ordinary hiking with a backpack is one of the least dangerous activities with regards to drinking water. First of all, most hiking routes are to be found in moderate climate zones, which don’t belong to the water-deficient regions of the world. The routes very often follow small streams or pass springs, which can easily be regarded as drinking water once the water quality has been assessed and the water, if needed, treated.

Calculating your potential water requirement and remembering to drink sensibly will allow you to get by easily with one and a half times your daily allowance—including a reserve in your backpack—without running out of water. If, for example,



With normal trekking outside of water-deficient regions, there is no need to constantly replenish water reserves. Ideally, this should be done during an evening break or at an overnight stop when you can take the time to assess and purify the water properly.

you are counting on two liters (half a gallon) of water for all your needs (drinking, cooking, etc.), carrying three liters of capacity will be plenty (while carrying a personal reserve is always a good idea). As you'll be using the water from the start, you don't have to carry the whole weight for the duration of the hike. Instead, the amount is reduced to about one liter during the course of the day. When there is time and clean water along the way (often breaks are deliberately scheduled by rivers or lakes), the water is replenished.

In water-rich regions, you should avoid the mistake of refilling your water bottles at every trickle and every puddle. Many people don't then take the necessary time to assess water quality.

In most temperate regions, it is sufficient to fully replace water reserves in the evening or the following morning. For example, water can be purified and bottled during a lunch stop or after decamping.

Besides, in many regions, water fountains have been set up at regular intervals for hikers; these can provide clean water, often tested for germs, from a clear mountain stream or spring via a tap, an open plastic hose, or a stone ledge.

Reserves and rationing

How much water to carry, therefore, always depends on physical constitution and average water consumption as well as the ability to collect and transport water. When traveling in more humid areas, for example, I always carry one to two liters of

water with me. Provided that there are water fountains at regular intervals along the way, the water will be replenished in the morning and in the evening. Over the course of the day, the water supply diminishes, with the added benefit of reducing the weight of the kit.

When traveling in a motorized vehicle in water-deficient areas, you should always carry several spare cans of water with you. In an emergency, fifteen liters (four gallons) of water, in a vehicle, will save you from dying of thirst for several weeks—assuming the right behavior and rationing.

I have learned this the hard way several times when I misjudged my water consumption while traveling through desert regions or when supposedly safe drinking water reservoirs contained only undrinkable water or none at all. Those were regrettable and formative situations that underline the importance of proper preparation and planning.

Following personal experiences, which at times have led to physical harm, my take-home message for longer trips to extreme destinations such as deserts and other water-deficient regions are the following rationing rules:

- Even if water can be replenished en route on a daily basis, keep at least one liter untouched as a reserve. If you ever need to open it, ration it strictly.
- As soon as you can foresee that the available water quantities are not going to last (for example, due to an unplanned break after an injury), start rationing. Don't wait until your stores are running low.
- Once you start rationing, you can collect your urine for around one day (but no longer, as it will be too concentrated then).
- Reduce your activity levels and, therefore, your daily water consumption to almost the basic amount during the first few days of a water shortage.



Water fountains designed for filling water bottles can often be found along popular trekking routes.

- As soon as it becomes clear that despite reduced consumption the available water is insufficient to reach the destination, drink as little water as physically possible (0.2 to 0.5 liters [7 to 17 ounces] per day, stretched with urine collected at an early stage.)
- Once you have opened the last liter of your reserve, further reduce your activity levels drastically, and drink no more than 0.1 liter (3 ounces) of water per day. With this reserve, coupled with the right conduct, it is possible to survive another week to ten days before dying of thirst—at the risk of physical harm. The last rations can be reduced further.

These figures are not to be regarded as dogma. They are the result of my own personal experiences in very different climatic regions. You should adapt these figures to your own personal water consumption and physical constitution and, through proper pre-travel preparations, avoid getting into situations that require rationing in the first place. It really isn't fun.

Rationing in an emergent water crisis

Water shortage:
slightly reduce water consumption + 1 liter reserve
Foreseeable water deficiency:
Collect urine, reduce water consumption down to basic amount, then reduce to minimum amount of 0.2 [7 fl. oz.] to 0.5 L [17 fl. oz.], drink diluted urine
Water crisis (supplies used up):
reduce consumption to 0.1 L [3 fl. oz.] or less
Reserve running dry:
reduce consumption to a thimbleful or less

Water stores

The suitable storage of drinking water for water emergencies is not only important for the residents of towns and cities where the supply of drinking water is not reliable (such as in economically underdeveloped regions in South America, or in mountainous regions without permanent access to snow-melt); it also matters to travelers in regions where there is no



If you need to take more than 10 liters (2.7 gallons) of water in addition to your luggage with you, there is virtually no alternative to a small handcart or well-marked water stores along the way.

guarantee that drinking water can be found en route. In the sense of an expedition “by fair means,” such stores can be part of an emergency structure that can be accessed in case of material failure or ill health requiring the tour to be aborted.

The factors of purification, preservation, storage, and volume are important issues that need to be addressed.

We should distinguish between water supplies stockpiled indoors—in times outside of water crises—and improvised water stores collected from a natural source and kept for future use.

Water stores as domestic reserves

There is a certain contradiction in the public perception between permanent water stores and everyday reality. In industrial countries, people are used to the idea that all food will eventually spoil. This is what the use-by date—printed on every item of food, be it ground beef or table salt, irrespective of its actual perishability—teaches us. Many food items are per definition nonperishable yet are still replaced or thrown out once their use-by date has passed.

The perishability of food implies a bacterial contamination; either its proliferation can be prevented until the use-by date by the addition of degrading preservatives, or the bacterial growth, slowed with correct storage, will exceed the

subclinical value (that which will not cause symptoms) some time after the use-by date, thereby rendering the food unsafe to eat. Less dangerous but equally noticeable is the effect of substances reacting with oxygen and, therefore, lessening the sensory appeal of a food, such as butter turning rancid.

This perishability, however, implies an original contamination as well as the presence of nutrients to sustain the germs. In accordance with the recontamination diagram and the basics of water preservation, clean water in sealed containers can scarcely become contaminated, as it lacks the necessary nutrients. Water in sealed cans, glass, or plastic bottles can in fact be kept for thousands of years.

Nonetheless, certain internet forums repeatedly claim that water should be replaced once it's past its use-by date. However, the only part that actually ages is the plastic, which is usually susceptible to UV light and should, therefore, not be exposed to direct sunlight. When sealed bottles and cans are stored away for the long term, they can be considered to be available for twenty to thirty years at least. Suitable ready-filled large-volume containers are available worldwide, including in developing countries. They are used, for example, as drinking water fountains in restaurants, hotels, and public buildings. When filling your own bottles or con-

tainers, it is important to remember that there will be a small initial contamination and to use preservatives that are not based on reactive **chlorine** compounds as they, too, can make the plastic brittle over time.



To create a domestic water store, simply buy commercially filled water bottles or containers. *Water doesn't go bad.* At worst, calcium and magnesium may flocculate (form small clumps) after a few years, but it is totally harmless.

Since storage space in such situations will be limited, the daily water allowances for a water crisis are relatively meager. It is certainly possible to manage with 1.5 to 2 liters per person per day.

In preparation for a water crisis, relevant books and various internet forums recommend storing daily quantities of fifteen to twenty liters (four to five gallons). This allowance includes water for cooking and washing food, personal hygiene, cleaning the dishes and the house, and so on, as well as laundry. In the case of a water crisis, you are unlikely to need to use this water for food preparation. Considering that even in remote developing countries it takes on average ten and a maximum of twenty days for aid organizations to become active, or until further improvised water treatment facilities can be organized, a permanent emergency water reserve of twenty liters (four gallons) per person will be ample.

Water stores as emergency provisions

If emergency stores are to be put in place as part of an expedition or for a desert trek, the situation is quite different. Since water is heavy and takes up space, it may be sensible to establish water stores at regular intervals along the hiking or driving route for the return leg of the trip.

It would be unwise to make firm recommendations for appropriate distances and volumes, as the requirements vary hugely depending on the type and purpose of the expedition. Anyone crossing a technically demanding desert in a 4x4 would do well to set up water stores every twenty-five to thirty miles to safeguard a potential return march in case of vehicle failure or loss.

Other types of travel—for example, trekking tours in water-deficient regions—often rely on water stored along the way to make a route altogether viable. Water stores can also provide security for desert crossings in case any unforeseen circumstances such as illness or injury require the trip to be abandoned.

There are two great differences between indoor water stores and temporary water stores for expeditions: On



Abandoned (?) water store in a desert. Without a label, it is impossible for an accidental finder to determine whether it is still needed.



Much better to add a permanent label that shows how long the water is needed for.

journeys, water stores often come from natural sources; they are exposed to the elements and are publicly accessible. In addition, they have to be more robust than, say, lightweight containers or glass bottles, which can be stored indoors. Short-term water stores must be sturdy enough to survive being thrown from road vehicles, or—in remoter areas—being placed by airplanes or helicopters.

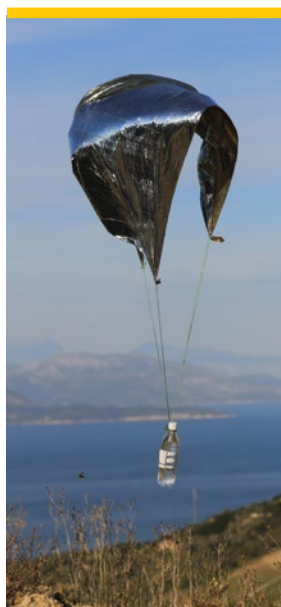
First of all, it must be decided if the water is to be preserved, or if raw water is going to be stored, which will require purification before use. I usually prefer the latter, where the ultimate usage of the water determines to which degree it needs to be treated.

When water is taken from a natural source and then purified, it will usually—in warmer climates and depending on the nutrient content—become recontaminated relatively quickly. Home-bottled water (even from a water filter) is never sterile, and in the absence of added preservatives, there will always remain a certain level of germs. This means double the effort if the water is purified prior to being stored.

Transparent PET bottles filled with the clearest water possible are suited particularly well to keeping contamination to a minimum. Left outside and exposed to direct sunlight for the storage period, they will self-disinfect through SODIS (solar water disinfection, see page 164) and therefore remain near-sterile. This method is not without its risks, though.

Exposed to UV light, plastic ages very quickly, and after a few weeks the material becomes dull; after a few months under a blazing sun, the bottles become brittle, making leak-ages likely. Given that such water stores are usually created for a specific project, a reduced “shelf life” is not normally a serious problem. Should you have to abandon your tour and attempt it again the following year, however, you will need to replace your water stores. Something else to consider: In theory, these water stores should be removed from the environment, but in practice they are often left behind, and so they need to be clearly marked with a time limit, written in English and in the local language.

Every desert trekker has happened across old, abandoned water stores but been unable to touch them because it wasn’t clear if someone else still relied on them. Understandably, such water stores are also opened and used by people in acute emergencies who happen to discover them. The label should, therefore, contain a simple message in easily understood terms stating how much of the stored water is a minimum requirement, and a deadline after which it can be freely used. This is one reason why this form of life assurance should be calculated fairly generously.



You should always allow for the loss of a bottle or two, especially when they are dropped from a plane or a helicopter. In my experience, bundles of three 1.5-liter bottles loosely tied together have proven to work well. Protected with an improvised parachute made with a 5-by-7-foot (160 x 210 cm) space

For each square meter (ten square feet) of parachute, a load of 1 to 1.5 liters of water can be dropped. For rugged terrain, it is advisable to err on the side of caution and use a larger parachute area.

blanket, the bottles will survive being dropped unscathed even from a great height. Having said that, you should nevertheless allow for the loss of at least one bottle.

It goes without saying that these stores will have to be marked on the map or by GPS in such a way that they can be located easily. It is also a good idea to include other useful items such as small food rations or additional first aid material, just in case.

Drinking properly

The big question with water intake is how to drink efficiently. In times of water shortage, you need to know when and how much to drink at each occasion. Generally speaking, the rule is that you should drink every time the body signals thirst, as the body is already experiencing water deficit. But this becomes impractical in hot regions when thirst is a constant, or at high altitudes where the sensation of thirst may be altogether absent. You have calculated your daily requirement; roughly this amount, but certainly no more, must be taken in over the course of a day to maintain the body's fluid balance.

In water-deficient regions (and only there), it may be counterproductive to maintain fluid balance, because the body will only revert to its wasteful "normal state." So there is nothing wrong with feeling a little thirsty all the time. You can tell from your urine whether you are drinking enough for your current physical activity level. If your urine is somewhere between deep yellow and orange, it indicates you are drinking too little. If it is clear and only pale yellow, you have been taking in too much water at once.

On reading this you will probably throw your hands up in horror (at least you will if you are a nephrologist). But in its normal state, the human body is less of a water reservoir and more of a tankless water heater. Excess water intake is a problem easily solved by the body, as fluid can be passed very quickly. By keeping a slightly **negative fluid balance**, we are actually conserving water.

This explains why generally you should not drink large amounts of water at a time. In the early mornings and eve-

nings, while it is cool and excess fluid can exit the body via the kidneys as well as the sweat glands, you may drink around half your basic amount. The rest should be divided over the hourly breaks when you stop to take a drink (instead of drinking on the go). This is also why I really don't approve of hydration systems for desert treks. These backpacks contain water bladders that are connected directly to the mouth via a plastic tube. In warm climates you have a dry mouth all the time anyway (that's not necessarily thirst), and so the temptation is to constantly suck on the tube—before long it will run dry. These bladders are useful as space-saving containers, but you should always drink from a clear flask, which allows you to keep a check on how much water you have been taking in.

If you are bothered by a dry mouth, try sucking on small stones, date pits, or buttons.

Nonetheless, do not drink too little at a time either. Breathing the arid air dries the mucous membranes in the mouth. By drinking only regular thimblefuls of

I recommend drinking from transparent water bottles; it is the only way to control water intake. One liter of drinking water remains untouched as the last reserve, but it should either be preserved or replaced regularly.



water, the fluid is almost completely absorbed by the mucous membranes before it even reaches the esophagus. You can try this at home: When you have a very dry mouth, take a small amount of water and swirl it around your mouth. There will be hardly any liquid left to swallow.

Dealing with a water emergency

Finding yourself in a town with a collapsed water supply, suffering a vehicle breakdown in a remote desert region, or realizing on a desert hike that you don't have enough water for the rest of the journey and don't reliably know where to find any are all examples of water emergencies.

It makes a big difference, of course, whether you are sitting in your air-conditioned hotel room in Brazil, and the water supply has been interrupted for more than just the usual couple of hours, or if you are propped up against a rock in the desert and are letting the last drops of water from your flask trickle onto your parched tongue. In principle, however, every interruption of the regular supply of water is a problem.

Since drinking water is needed by every human being on a daily basis and in relatively large amounts, it is often only a matter of hours or days before all the stocks of bottled water in the shops in areas of crisis or disaster zones (such as after floods or earthquakes) are either sold out or looted. Consequently, even a presumably safe situation can quickly turn into a potentially dangerous one.

What is important for you to realize is that water may become dangerously scarce. To evaluate the risk, you can either calculate (how many days' worth of water remains in the can, how many days until I am rescued?) or estimate the impact (after an earthquake, the water supply may be interrupted for considerably longer than expected).

We will divide these different and barely predictable water-scarcity scenarios into three groups, loosely based on the types of access to drinking water as defined by UNESCO.

Water stress

You still have some drinking water but assume that it will run out sooner or later. Your surroundings contain liquid water, or combined water (contained in sediment or plants) that probably still has to be converted into a potable state. Your calculated daily demand is not safeguarded for the long term, but it's likely to be satisfied with relatively little effort.

Such a situation is likely to occur with water outages, floods, or journeys where for a certain period of time only insufficient water can be carried. In effect, this includes all multiday trips relying on streams and rivers for the supply of drinking water.

Water shortage

You only have a limited amount of drinking water left. You suspect there are water sources nearby. Water is available in liquid or combined form but still needs to be extracted with the right technique and made potable.

Extracting sufficient water for your daily needs with normal to slightly reduced activity levels is possible.

Water crisis

During a trip across the desert, you have no or only very small reserves left. It is not possible to obtain sufficient amounts of liquid water. A water crisis is always a question of survival.

In a water crisis, your number one task is to keep the body's water consumption to a minimum. The need for water to excrete waste products and control temperature must be greatly reduced. Ration any obtained water from the start. Always remember to keep any movement and exposure to heat to a minimum. Rest in the cool shade during the day and limit all absolutely necessary activity to the coolness of the night.

If available, use a tent or blanket to create a double-walled canopy to act as an insulating roof. In sand or gravel deserts, dig as deep a pit as possible during the night and cover it loosely with the canopy, creating a shelter to rest in during the day. This way, body heat can escape from the pit to the

top. Overheating and sunstroke must be averted at all cost. Don't talk, don't eat, just "vegetate" in the shade and hope for rescue. In this state, a few drops of morning dew or previously collected urine will keep you from dying of thirst for a few more days. Here, every drop really counts.

In a water crisis, the only option is to act *appropriately to delay terminal dehydration for as long as possible*.

In times of water stress or water shortage, it may also be beneficial to conserve water, but knowledge, previously learned skills, as well as resourcefulness and the ability to improvise, are the crucial factors that will allow you to make sufficient water drinkable. That is what the following chapters are all about.



Not only during a water crisis: Midday rest and light-colored clothing help to keep the need for water to a minimum on fully self-sufficient treks. On the left: carts with sixty liters (sixteen gallons) of drinking water each for ten days in the desert.



2



How to find water



How to find water

If you have ever traveled independently in remote areas, you will have had to go looking for water on day two or three at the latest.

Unless you find yourself in an **arid climate**, finding water is usually not a difficult task. In most cases, obtaining drinking water means assessing the quality of and treating available and clearly visible water from large rivers or lakes. This chapter, however, deals with the less common scenario in which you have to physically search for water.

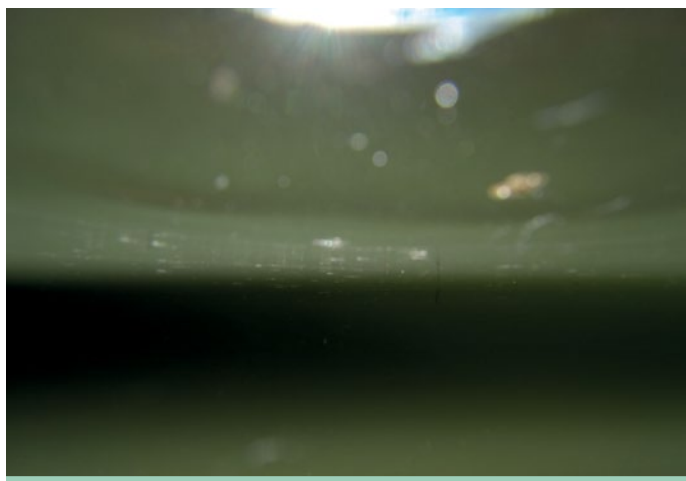
Properties of water

Water is subject to simple physical laws. Its behavior is predictable, and its important elements can be manipulated. Before we delve into the details of the search for drinking water, we need to understand some of its properties.

Density (i.e., mass per volume): At 39.2°F (4°C), water, or more specifically, pure, gas-free water, has a density of just under 1 kilogram per liter (2 pounds per quart), or 1 metric ton (2,205 pounds) per cubic meter (264 gallons). The density of liquids depends on their temperature and on whether they contain any dissolved substances (known as **solutes**).

The colder water is, the heavier it is—up to a temperature of 39.2°F (4°C). At this temperature, water is at its heaviest (i.e., it has the highest density). If warm water is carefully layered on top of cold water, the warmer water will float on top of the colder layer, separated by a thermal layer called thermocline. You may have experienced this effect when swimming in a lake: at a certain depth, the water suddenly gets very cold.

When water is cooled to below 32°F (0°C), it freezes. This in turn reduces its density—at 900 grams (1.98 pounds)



per liter, ice is *considerably lighter* than water and floats on top of it.

These values only apply to perfectly pure water. The properties change with any dissolved substances or gases it may contain.

Thermocline in a highly eutrophic body of water (nutrient-rich and supporting dense plant growth). The water layers with different temperatures do not mix immediately; instead the (dark) warm, nutrient-rich layer lies on top of the cold layer.



Fluidity: Another important property of liquid water is that it really is “very fluid.” It has a low viscosity and a high fluidity (compared to oil or honey, for example). That is why it usually collects in the lowest place above water confining layers in the ground. In fact, there are only very few truly impermeable soil layers—for example, solid rock, fine silt, and clay. Yet even where the water flow is blocked below ground, the reservoir will eventually become full and either overflow subterraneanly or break through the ground in the form of a spring. Often, water will trickle through fine cracks and pores in ostensibly solid layers and travel downhill at a rate of a few meters a day, following the most direct route.

As per the principle of communicating vessels, in which liquid settles at the same level regardless of the shape or volume of connected containers, the level of open water is a good indicator for the minimum and maximum groundwater

As per the principle of communicating vessels, the water table in an aquifer is the same in all locations, even if there are obstructions in-between.



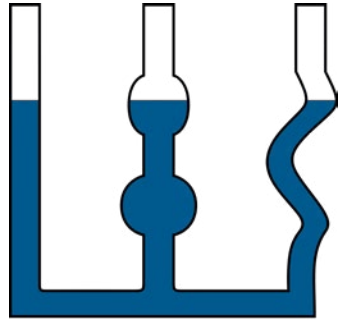
levels within several hundred meters, even if there are large rocks or sedimentary layers in the area.

Exceptions are freshwater

lenses (convex layers of fresh water floating above denser salt water; see page 45) and fast-flowing rivers in rugged or sandy terrains. Here, the groundwater table around the surface water drops quickly.

A further important and observable property of water is defined implicitly. Without water there is no life on Earth. And it doesn't matter if the water is freely available in liquid form, as vapor in the air, or contained within plants, sediments, and rocks.

Wherever there is any form of life, water *must* be available somewhere.



The following questions must usually be considered when looking for drinking water:

- Where do any present living organisms get their water from?
- How can water from different sources be extracted for our needs with the least possible effort?
- Is any raw water extracted from the environment safe to drink or must it be treated beforehand?

Answering these questions, as you will see in the following chapters, can sometimes be more complex than the actual locating of water.

Taking its special properties into account, the search for water is particularly promising in the following places.

Typical **aquifers** and **aquicludes**:



Aquifers: Gravel and compacted sand as well as coarse-grained sedimentary rock with a low silt content are natural aquifers (left). Fine-grained rocks such as clay, compacted shale, and limestone, however, are aquicludes (right).

How to read terrain structures

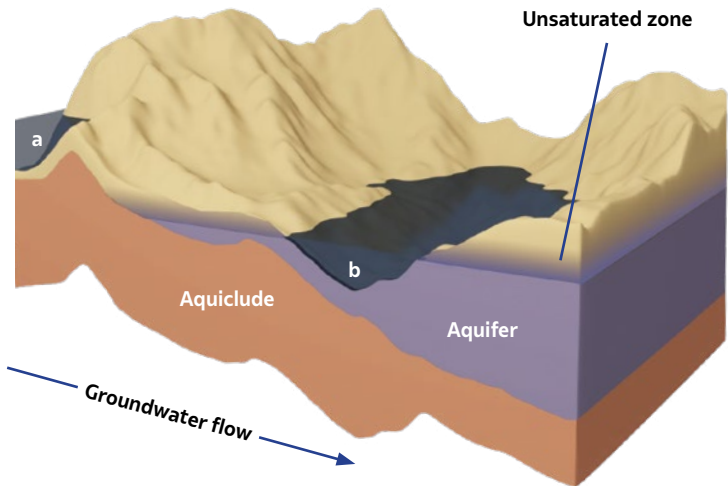
With the exception of large rivers or lakes, you will rarely find ready-to-drink water in arid regions. Often potential sources are only recognized by literally stepping into them. Moreover, many other signs such as soil layers, indicator plants, and animals (see page 38) can only be identified in the immediate proximity.

To find likely places, it is important to consider the geological features of the environment. As you know, water always flows downhill and collects or disappears (below ground) at the lowest point. Looking around the area, you will easily spot a few typical signs of existing surface water or subterranean water levels.

When studying geological features, it is worth knowing that—as a rule—rock, confining soil layers, and so on tend to

continue underground and under eroded layers, gravel, sand, or plants in the same pattern as they are visible above ground. Try to ignore the soil layers above a confining layer and imagine how it may continue below them.

If, for example, you estimate an intersection of two rocky mountainsides to be underneath some erosion rubble between the slopes, you can mark this point as a likely runoff point. It should be noted, however, that water won't necessarily break through to the surface at this point but may well be flowing off in the sediment many feet below. Nevertheless, these natural reservoirs have the enormous advantage that due to the lack of sunlight they are not affected by **evaporation** and may therefore hold water for decades after the last precipitation.



Sometimes water collects above the water table when it can't drain away quickly (a). As a rule, the water level of open bodies of water (b) indicates the local groundwater level. The water mass usually lies between a confining soil layer (aquiclude) and surface water level, except for in some cases the "unsaturated zone" (a moist, but not completely saturated soil layer) where water rises above the surface water level.



Trenches in a mountainside: The intersection between the rocks is the only course any water can take. It suggests the location of a water runoff either above or below ground.



Canyon/gorge: Indicates water erosion following heavy precipitation events. Follow the dry riverbed until you come to a barrier across the river. If there is a subterranean water reservoir present at all, it will be here.



Mountain saddle without natural runoff: Open mountain lake or water reservoir under the sediment with very slow runoff through the bedrock.

HOW TO FIND WATER



Overlapping cliffs with deep valleys: The intersections are likely points for a surface river or pond.



Depression in an extensive plain: If there is any subterranean water present at all, it will be found at the lowest point of the depression.

Indicators for the presence of water

Following the tracks of wild animals will usually lead you to water sooner or later. Unfortunately, however, there are some mammals, especially in arid regions, that have adapted to alternative water sources or can go without water for long periods of time, so animal tracks cannot be considered a reliable indicator per se. One extreme example is the desert-dwelling kangaroo rat, which obtains water by recycling the condensed water suspended in its breath in its nasal mucous membrane. Larger mammals sometimes travel many miles to reach the nearest watering hole.

In the context of water, there are a few stories going around regarding insects that should not be accepted unquestioningly. It is common knowledge that bees and mosquitoes invariably depend on water, but that is true mainly for species in moderate and humid climates. Individual animals as well as entire swarms may, however, be blown by the wind into water-free zones where they can survive for weeks or months without water.

Important indicator plants and animals	Notes
Ferns, mosses, horsetails	Need water for development
Fast-growing water meadow trees (e.g., poplar, willow)	Often shallow-rooted species
Pandanus	On beaches often an indicator for freshwater lenses
Taro and other (large) Araceae	Very large numbers of plants with large foliage are generally good indicators for moist soil
Reeds, bulrushes	Often found along eutrophic waters (nutrient-rich and plant-dense)
Tree ferns	Survive only short dry spells
Rats	Disease carriers!
(Water) snails	Mainly larger species often with epiphragm (a sealed shell opening)
Cockatoos, pigeons, macaws, etc.	Mass gatherings are usually a sure sign of water and are audible and visible from long distances

In the Australian outback, for example, bees are not a reliable indicator for water in the vicinity; besides, many insects and arachnids can get by with a few rare and microscopically small dew drops for their development stages and water supply.

Some creatures, however, are particularly useful water indicators either in liquid form or contained in the soil. These are either stationary—in other words, plants, which by nature can't move to look for water—or animals that occur in very large numbers in one area even though they are extraordinarily mobile: birds.

The indicator organisms presented below occur in various climate zones around the world and can usually be found wherever some kind of usable liquid is available.

	Region	Indicator for
	Worldwide	Intermittent presence of liquid, moist soil
	Temperate zones	Moist soil or surface waters
	Oceania	Rivers, lakes, marshlands, freshwater lenses
	Southeast Asia	Rivers, lakes, marshlands
	Worldwide	Permanently moist soil, often liquid water
	Tropics, subtropics	Moist soil
	Worldwide	Slow-flowing rivers, lakes, canals
	Worldwide	Moist soil, high water table
	Worldwide	Rivers, lakes, marshlands

Important indicators for moist soil



In temperate regions, reeds and especially the compact rush pads that are visible from afar are important water indicators. They typically grow in habitats with very moist soils. There is usually a good chance of finding liquid water in their vicinity.



Globally, reeds, or cattails, are easily identified by their long, broad leaves. Their roots don't go as deep as the ones of canes and therefore prefer moister soils. Their ideal soil is wet to marshy. The plant itself is also a great water substitute.



Around the Asian and African equator, taro and other large-leaved Araceae are important water indicators because they need a lot of water. In wet ground it will grow in entire fields. Individual plants of a less-saturated green indicate at least locally moist soils.

HOW TO FIND WATER



Tropical tree ferns (like all ferns) don't survive long dry spells and tend to settle on hillsides and in valleys on permanently moist ground. Therefore they also indicate subterranean water flows in mountainous regions.



Even desert-dwelling palm trees need water. Due to the fluctuating water table, they can be found in areas where there is no surface water left. Even if all there is here is ruins, there must be water somewhere.

Potential groundwater locations

The easiest option for obtaining water is a spring. Springs are places where the subterranean water is confined in such a way that its natural flow is forced to continue above ground. Likely places can often be spotted easily by looking at the geological structures of the landscape.

Springs come in various forms: They may be “rheocrene,” where the water emerges from the ground in a fountain or a trickle. More common, however, are springs that discharge into a pond or a marsh, where the groundwater table lies above ground level.

Seepage springs are often small surface bodies of water without a clear inlet or outlet. They overlie the ground on confining soil layers and are not easily distinguished from pooled precipitation. In theory this doesn’t matter, as water is water; however, it is helpful to know how reliable water in a particular location is—in other words, how long it will be there for, given that recently accumulated rainfall will quickly seep into the ground or disperse.

One indicator for a reliable spring is the relatively low temperature of the water (ca. 41 to 50°F [5 to 10°C] in temperate zones, ca. 68°F [20°C] in the tropics) compared to the ambient temperature.



A torrent about to dry up. With loose soil structures, the river bed will carry much more water beneath the surface than might be expected.



A torrent in the Negev Desert. A large river flows along here, about three feet below the surface.

A confining soil layer underneath loose stones and rocks can lead to water being stored in and discharged from lake- or riverlike structures without it being apparent above ground. This is the case where permeable rubble, river gravel, or sand form a thick layer above the aquiclude.

This setup is commonly found with fast-flowing streams or torrents, which are particularly prevalent in water-deficient areas: Immediately after a precipitation event, a torrential stream flushes stones and sediment through valleys and disperses it over entire plains. Yet after a few days or weeks, the water has all but gone. Long after the last drop of rain has fallen, a constant flow of water, sometimes several feet beneath the surface, can often be found under easily removable rocks and gravel.

Wells

You probably don't need instructions on how to use a "normal" well. And it probably goes without saying that, in case of doubt, wells are private property and that permission to extract water must be sought from the proprietor in advance, especially in water-deficient regions, and that water should not be extracted from a well for the purpose of washing one's feet or the car.

The term *well*, however, is used to describe all artificial attempts to reach the groundwater table. Here, the term generally refers to a simple hole in the ground that can be dug to a depth of one to two meters (three to seven feet) without any great effort. It is important to find a *likely* suitable location *before digging the well* as “trial digs” are inefficient and only increase the demand for water.

Infiltration wells

When searching for water, digging only makes sense where the geological features of the terrain (see “How to read terrain structures”)—or other reliable factors (freshwater lenses, water indicators, moist soil)—suggest that the water table is relatively close to the surface. In subtropical regions, water may not be extractable as a liquid from a hole in the ground but instead may have to be collected in the form of moist earth or mud from the **unsaturated** zone using a suction well.

One sure sign of a high groundwater table is obviously the presence of a body of water (including a heavily polluted one) in the immediate vicinity, which can be used to estimate the level of the groundwater table.

In this case, you will need to dig a well at a distance of fifty to a hundred meters from the body of water. Due to precipitation, the groundwater level is often slightly lower around the edge of a surface water, so a hole must be dug, away from the edge, that is *deeper* than the water level of the surface water. As it spreads horizontally through the sediment, the water will be filtered, and any potential contaminants will be removed by soil bacteria on its way to the extraction site, in a similar way to rainwater filtering through the ground on its way to the groundwater. Water extracted from a well dug a certain distance away from the main river is often safe to drink without further treatment, even if the river is heavily polluted, although this obviously does not apply to chemical or industrial pollutants.

While digging, pay attention to any foul smells emanating from the soil layers. If you detect any, try further away from the river or lake, or on the opposite side. Foul-smelling



A few yards away from the edge of a polluted body of water, clean drinking water can be obtained from the ground. This image shows black soil layers with anaerobic nutrient decomposition—in this case you should dig a new well a distance away.

soil layers indicate that at high water the polluted water extends to the extraction site, or that large amounts of nutrients may have been blown to the edge by wind.

Once the well is dug, the raw water should be left to collect and settle at the bottom of the pit before skimming it off and, depending on its quality (see Chapter 3), treating it further.

Suction wells

If there is not enough moisture in the sediment to extract liquid water (only mud or waterlogged loam), you can construct a suction well: Cover the bottom of the hole with plant material or fabric from clothing and place a piece of cane, plastic pipe, or similar inside. Refill the pit with tightly packed soil. You should now be able to suck liquid water from the soil into the material and from there through the cane or tube into your mouth. If this proves unsuccessful, you can, if necessary, swallow the moist earth directly or squeeze it through some fabric, or, if there is not sufficient water to do this, separate the water by way of **distillation**.

Other sources

Freshwater lenses

The term *freshwater lens* may make you think of underwater photography, but it actually refers to a physical phenomenon that can safeguard your drinking water supply on islands and remote beaches.

In order to understand where and when you can expect to find this source of fresh water, you need to deepen your understanding of density: If you dissolve a soluble substance in water, it breaks down into individual molecules or electrically charged ions. Thanks to the proper motion of water, these minute particles disperse between the water molecules, leading to a change in its density.

Imagine you are building an improvised water filter and are adding a measured amount of coarse gravel into a container and mixing it with the same *mass* of fine sand. The weight of the mixture will double, but the *volume* will be almost the same as before you added the sand. The sand has enough space to fit in and around the gaps between the small stones without displacing them. This process caused the density, or the *weight per volume*, to double.

Now, instead of the sand, take a measured amount of table salt (sodium chloride) and add this to the same volume of water. The salt will partially dissolve. You can visualize the salt molecules splitting into Na^+ ions and Cl^- ions (a process known as dissociation) and dispersing in and around the H_2O molecules. Just as with the gravel and sand, the total volume of the mixture increases very little, while the total weight of the two combined components has doubled. Hence it follows that salt water has a higher density than fresh water; while one liter of fresh water weighs around 1 kilogram (2.2 pounds), the same volume of seawater weighs around thirty grams (one ounce) more.

As you know, Styrofoam (density about fifty grams per liter) floats on water, while lead (density about eleven kilograms per liter) sinks to the bottom. The same happens when

you add salt water to fresh water. The heavier salt water sinks below the lighter fresh water.



Fresh water (red) has a lower density than salt water and “floats” on top. A layer of brackish water forms where the two layers meet.

If you pour a glass of fresh water into the sea, it will combine with the salt water within seconds. Even if you pour it very carefully onto the surface, it will spread out like a thin layer of oil and get mixed in very quickly due to the **thermal agitation** of the molecules. You would need a very large amount of fresh water or a very large temperature difference for a separation layer to form.

The situation looks very different, though, if you pour fresh water into a buffer medium—such as sand—saturated with salt water. The fresh water will slowly disperse the salt water, creating a zone with mixed **brackish water**. Soon a layer of fresh water will lie above the heavier (or rather, denser) salt water in the sand.

Within the buffer, a stable, watch glass-shaped layer forms on top of the saltwater with a clearly defined mixed-water zone on the edge. The upper freshwater level is always considerably *higher* than the salt water level. This phenomenon is called a freshwater lens, or Ghyben-Herzberg lens. They develop where porous soils such as sand or karst meet the sea, on beaches or islands, *providing the area has seen at least occasional rainfall in the previous decades*. Seawater on its own cannot produce fresh water in the sand, something we will look into more closely later on.

Even small sandy islands of just a few hundred meters in diameter can harbor huge freshwater reservoirs. In contrast to many groundwater resources, freshwater lenses do not depend on impermeable soil layers such as rock or clay, as the salt water under the island acts as the confining layer.

A few things to note when looking for fresh water on the beach: The level of natural freshwater lenses is *noticeably* higher than sea level. The brackish water zone is usually on the *interior* of the island or at beach level.

It is therefore of little use to dig in the lower sections of the beach because, on the one hand, this will be below the freshwater source—the actual “groundwater” being the underlying seawater—and on the other, the mixed-water layer is more likely to be found in the vegetated regions. Instead, look for the lowest point on the island plateau—above sea level.



Often small pools can be found here, or at the very least water indicators (see “Important indicator plants and animals,” page 38).

A beach closed off by cliffs harbors a large freshwater lens formed after precipitation. The freshwater level here is around one or two feet above sea level.

On very small islands, you may find that there are no true freshwater lenses and that the available water reservoir consists purely of brackish water. In this case it is important to assess the salinity to determine if and how the water is to be desalinated.

Submarine freshwater sources

Freshwater sources also occur on beaches on the mainland. Even in totally dry regions without any precipitation at all, subterranean rivers flow hundreds of miles from the interior toward the sea. In tropical regions especially, rain falling in the mountainous interior will run off not only via rivers but also through the bedrock in the form of seepage water.

Clues as to the existence of such subterranean freshwater sources can be found in the geological structures of a landscape. Trenches between mountains that run in the direction of the sea, or wide-ranging depressions in the area that slope gently toward the beach usually point to the fact that at a certain point water flows into the sea. Sometimes, due to the counterpressure of the sea, the water flows very slowly and has therefore been traveling through the ground for many

hundreds or thousands of years, which is why even in areas without any current vegetation the ground may hold large amounts of water.

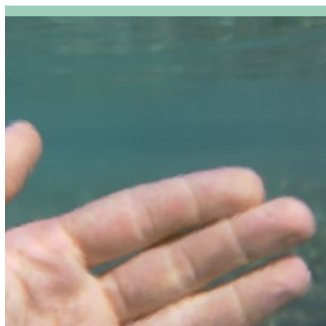
You can also find evidence of fresh water by looking at the seawater immediately below the beach. When swimming or wading in this zone, you will sometimes notice “cold pockets,” or wide fluctuations in water temperature. Upon inspection you will see opaque streaks in the water. The effect is caused by the inflow of large amounts of fresh water, which due to its higher density and lower temperature—subterranean water being considerably colder than seawater—does not immediately disperse in the sea but forms temporary, stable “pockets” in the water.

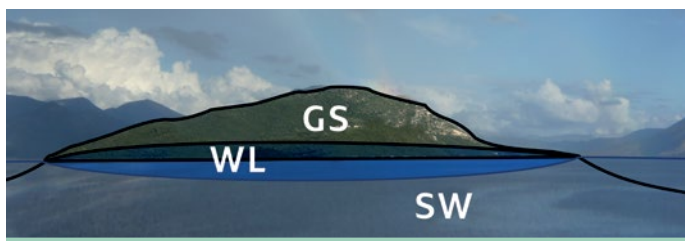
The process for collecting this water is similar to that for freshwater lenses, the only difference being that you don’t need to dig quite as far away from the beach. Owing to the constant flux from the interior, the salt water in the sand is being pushed toward the sea. And while the brackish water zone in these locations is wider than with static freshwater lenses, it is often closer to the sea under the surf zone.

Previously, the presence of fresh water on beaches used to be explained—and in some survival guides still is—by claiming that the sand was somehow able to “filter” the salt out of the seawater. The farther away from the beach one looked, the less salty the water would be. Given the chemical and physical laws at play here, this is of course nonsense.

If sand were really able to absorb or filter salt, the constant flow of salt water through the sand would leave behind a ridiculous amount of salt (thirty grams per liter). Over the course of thousands of years, enormous amounts of salt would have collected on every beach—there would be mountains of millions of

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Opaque streaks in seawater are a sure sign of a submarine spring.



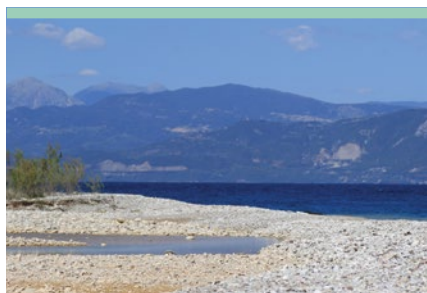


Ghyben-Herzberg lens on an island: The salt water (SW) underlying the island pushes the watch glass-shaped groundwater level (GS) above sea level. The freshwater lens (WL) can contain many millions of gallons of drinking water.

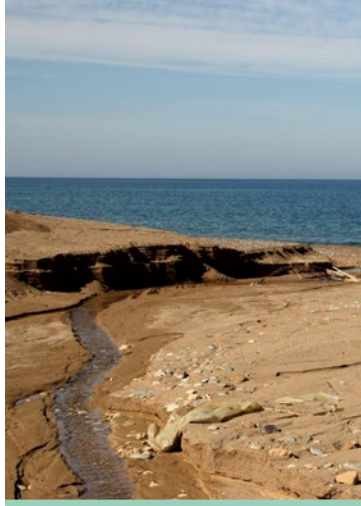
tons of salt everywhere. Since matter does not simply disappear, and salt does not evaporate at normal temperatures, the desalination of seawater using sand would be a miracle.

***In the absence of a freshwater source inland that empties into the sea, you will not find any fresh water on the beach. Any water you find when digging fifty to a hundred meters away from the sea must be at least brackish. If you only find pure salt water here, then there is no fresh water present, and there is no point digging further inland.***

Fresh water layered above salt water in the ground is a very valuable resource. In contrast to ordinary groundwater, it doesn't require a confining layer to push the water to the surface. Even if it has traveled underground many meters below the surface, it is slowly raised by the saltwater level underneath until it is actually above sea level by the time it nears the beach. These sources are usually free from any contaminants and typically not exploited inland, as they are too far under the surface there.



A special kind of freshwater lens can be observed near river mouths on gravelly ground: The seawater staunches the flow of the river and raises the water level (here about three feet) above sea level.



A stream seeps away in the immediate vicinity of the sea, emptying invisibly into the salt water through the sand. Large rivers may flow below ground for many miles before they reach the coast.

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In this manner, it is therefore possible to find drinking water in remote locations near the sea—

even if the environment is sandy and seemingly barren. In the event that rivers and groundwater are heavily contaminated—for example, in industrialized regions of developing countries, or after a disaster anywhere, you can still find clean and pure fresh water that isn't fed by surface water or groundwater reservoirs under the beach.

## Ice and snow

When traveling in cold regions, ice and snow play an important part in providing drinking water. Where temperatures are permanently below freezing, finding water is usually not a problem. The **absorption capacity** of the air is reduced to a minimum, so even small amounts of moisture form as fog in the air and as frost on the ground (which is why your breath becomes visible when exhaling at low temperatures). If the humidity is very low, a surprisingly large amount of frost can be lost through **sublimation** (passing directly from solid to vapor state), but often the remaining ice crust covering plants or rocks is sufficient to meet one's daily water requirement. Where there are pockets of snow or even a solid blanket of snow, there is obviously no need to collect frost. Therefore the issue is less one of *where* to find water in cold regions and more of *how* to convert it into its usable, liquid state.

Of course, ice can just be melted, but a few points must be considered: Even if we assume a low daily requirement of 2.5 liters at sea level, a lot of energy is required to melt that amount of ice.



With the presence of a solid blanket of snow, it is preferable to try to reach the meltwater flowing in gullies or gorges to save energy.

The enthalpy (or heat) of fusion is a physical quantity that describes how much

energy is needed to turn a substance from a solid to a liquid state. To melt one kilogram (2.2 pounds) of water ice at 32°F (0°C) requires around 330,000 joules (J). More energy is needed to warm that ice to melting point in the first place and more again to heat the water to body temperature. The melted water will reach body temperature at the latest after it has entered the body, and to heat up anything requires energy—either by heating it on a stove or inside the body with food.

The specific heat capacity of water ice is around 2,000 joules per kilogram per **kelvin** (K) of warming; that of liquid water is around 4,200 joules.



Every summit with snow and ice must inevitably have a large runoff. It is better to look for water in the valleys rather than climb up the mountain.



If the temperature drops at high humidity levels, fog will form in the air.

The equation for melting one kilogram of ice (at 14°F [-10°C]) and heating the water to 59°F (15°C) looks roughly as follows:

**Heating one kilogram ice to melting point:**

$$2,000 \text{ (J/kg}^{\circ}\text{K)} * 1 \text{ kg} * 10 \text{ K} = 20,000 \text{ J}$$

**Melting one kilogram ice into water:**

$$\text{Enthalpy of fusion of 1 kg water} = 330,000 \text{ J}$$

**Heating the water from 32°F (0°C) to 59°F (15°C):**

$$4,200 \text{ (J/kg}^{\circ}\text{K)} * 1 \text{ kg} * 15 \text{ K} = 63,000 \text{ J}$$

In total, this means that for each liter of water obtained from ice, 413 kilojoules (kJ) of energy are needed. With an energy efficiency of 25 percent, this corresponds to the following fuel requirements:



Due to the air's low absorption capacity at low temperatures, a large amount of fresh frost can often be harvested in the mornings. If the temperature stays low, however, the frost will sublime quickly.

**Model calculation for two people and 3.5 liters drinking water each**

$$\text{Fuel requirement: } 2 \text{ people} * 3.5 \text{ L} * 40 \text{ g fuel (gasoline)} = \mathbf{280 \text{ g gasoline/day}}$$

If you are planning on melting ice or snow for your drinking water supply en route, you must allow for the appropriate fuel requirements.

In addition, every liter of consumed water requires around ninety-one kilojoules (or twenty-two calories) to equalize the temperature difference between the water (59°F [15°C]) and the body's core temperature. The body needs this energy in the form of extra food.

This also highlights why water ice should always be melted over a flame and never in the mouth: The energy needed is the same.

**For every liter of water melted in the mouth, the body will burn (at least) an extra 480 kilojoules (or 115 calories) or so, which is the same as around 100 grams (3.5 ounces) of cooked pasta.**

## Humidity—dew

It may seem hard to believe, but almost everywhere on our planet, the air in the atmosphere contains enough water to sustain a variety of organisms. Water in the air is most noticeable as clouds or precipitation, which we will get to later in this chapter. Rain, however, forms at high altitudes and not on the ground, and there are climatic zones where it effectively never rains at all—or at least not when it is needed.

The air consists of gases including nitrogen, carbon dioxide, and oxygen as well as water vapor, with the percentage of water being higher than might be presumed. Even at low temperatures, oceans, surface waters, and also apparently dry surfaces such as desert sand or rock are constantly releasing water molecules into the air immediately above the ground. They go unnoticed as they are invisible, in vapor form—that is, until the air becomes saturated and can absorb no more water. If more water is released into the air, it forms as fog or steam.

In the weather forecast, you will hear this phenomenon described as relative humidity, given in percent. However, this value says nothing about the *actual moisture content* of the air. For example, the current relative humidity in New York City at the time of writing is 80 percent. This does not mean that one liter or kilogram of air contains 80 percent water, but rather that the air contains 80 percent of the moisture it is capable of holding at a certain temperature (in this case 61°F [16°C]). This relative humidity is very variable; it increases as the air cools down and decreases as the temperature rises.

*Warm air can hold more moisture than cold air.* Therefore, a larger number of water molecules are needed to reach saturation level (100 percent relative humidity) in hot air than in cold air. That is why in warm regions the relative humidity is often quite low, while temperate and cold regions tend to see higher values. Nonetheless, the actual moisture content in the air may well be identical.



Moisture in the air will form as fog when the air cools down to a point where the relative humidity is above 100 percent. An impressive example can be observed on open waters. In the mornings, a thick screen of fog floats above the water: It is in fact evaporated water oversaturating the air above it.

The physical values pertinent for extracting water are summarized in what is called the dew point, which describes the temperature in connection with the relative humidity at which fog will form in water-saturated air.

Without delving any deeper into the matter, the following details are important for our purposes:

When saturated air is cooled down from 86°F (30°C) to 32°F (0°C), up to twenty-five grams of water may be collected per cubic meter of air.

| Maximum water content in the air at different temperatures |                     |
|------------------------------------------------------------|---------------------|
| 32°F [0°C]                                                 | 5 g/m <sup>3</sup>  |
| 50°F [10°C]                                                | 10 g/m <sup>3</sup> |
| 68°F [20°C]                                                | 18 g/m <sup>3</sup> |
| 86°F [30°C]                                                | 30 g/m <sup>3</sup> |

The following apply:

- The warmer the air, the more water it can absorb.
- Warm air with a high relative humidity only needs to cool down a little for dew to form.
- Air with low relative humidity must be cooled down much further for dew to form.

## Dew point

The table on page 57 will help you estimate how efficiently water can be collected from surfaces and what the maximum temperature for those surfaces is for water to become available on them in the form of condensation.

For example, at 40 percent relative humidity and an ambient air temperature of 95°F (35°C), a surface must be cooled down to 72°F (22°C) using cool sand, mud, or gray water to be able to collect water from it. At 50°F (10°C) air temperature and the same relative humidity, the condensation surface would need to be brought down to below 32°F (0°C).

You don't need to learn this table by heart. Nevertheless, you should familiarize yourself with some of the values to estimate if extra effort is required to collect condensation or if it is possible to obtain water from the air at all.

### Extracting water from the air

One way of extracting water from the air is to use fog catchers or condensation surfaces such as the body of a vehicle. One precondition is that the starting air temperature must be rather low. If the day temperatures are high, the night has to be quite cold. This effect makes this method particularly efficient in temperate or cold regions, or in hot climate zones with very high humidity levels.

At the values mentioned above, a temperature of around 40°F (4°C) and 92 percent relative humidity, the temperature only needs to drop by one or two kelvin for dew to form and for humidity to turn into usable water. During the summer, at 86°F (30°C) and low humidity (for example, 40 percent), the temperature would have to drop by 20°F (13°C) overnight.

High temperatures with very low humidity mainly occur in warm **semiarid** or arid regions. Yet practical experiments have shown that even there, water can be collected from condensation on fog catchers: Take any objects (such as pieces of metal, water containers filled with sand, etc.) that have cooled down overnight and, in the morning, bury them in cold sand. At noon, when the moisture in the sand evaporates under the sun, place them in the shade. Even in sandy deserts, several milliliters of condensation (up to a shot glass full) will gather on the cool objects. Obviously, the water will have to be collected immediately. The amount of water may not be sufficient to cover your daily requirement, but in a water crisis and with physical rest it is enough to delay death from thirst by a day or two—in other words, hopefully until rescue.

Dew collected from relatively clean surfaces (plants, rocks, fabric, etc.) can usually be consumed without prior treatment.

Important values for condensation on surfaces at different air temperatures and humidity levels (all values given are maximum temperatures)

| Humidity/<br>Temperature | 20%         | 40%         | 60%         | 80%         | 95%         |
|--------------------------|-------------|-------------|-------------|-------------|-------------|
| 32°F [0°C]               |             |             | 21°F [-6°C] | 30°F [-1°C] | 34°F [1°C]  |
| 41°F [5°C]               |             |             | 30°F [-1°C] | 36°F [2°C]  | 39°F [4°C]  |
| 50°F [10°C]              |             | 27°F [-3°C] | 37°F [3°C]  | 45°F [7°C]  | 48°F [9°C]  |
| 68°F [20°C]              |             | 43°F [6°C]  | 54°F [12°C] | 63°F [17°C] | 66°F [19°C] |
| 86°F [30°C]              | 41°F [5°C]  | 63°F [17°C] | 70°F [21°C] | 79°F [26°C] | 84°F [29°C] |
| 95°F [35°C]*             | 54°F [12°C] | 72°F [22°C] | 81°F [27°C] | 90°F [32°C] | 93°F [34°C] |

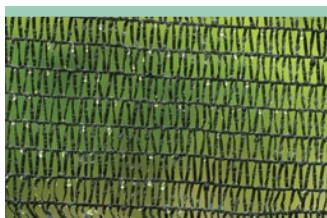
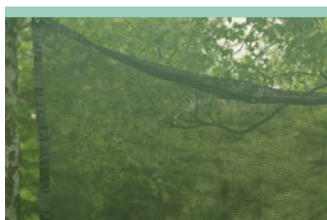
\* To be used with sandpit distillation (see page 189).

## Fog catchers

Setting up a fog catcher is a worthwhile enterprise in all regions and seasons with a relatively cold climate and large temperature differences between day and night. Depending on the season, fog catchers may also prove useful in dry deserts.

Fog catchers are large, sail-like structures that allow the water vapor in the air to condense onto it during the night. Suitable materials include tarpaulins, rescue blankets, fabric, shade cloths, and metallic foil; strung vertically between trees, poles, and so on, they all make good fog catchers. As the

air cools overnight, its relative humidity rises slowly but surely toward saturation. When individual water molecules come into contact



Fog catchers are best hung up in valleys, as fog tends to last longer here. When using foil or a plastic sheet, the lower part can be folded over to create a collection vessel. More suitable, however, are fine fabrics such as shade cloths through which the moist air can pass and condense on the individual threads.

with particles (say, with dust), they act like condensation seeds, or, in freezing temperatures, like crystallization seeds. This phenomenon can be observed in vapor trails (called contrails) that form in clean air at high altitudes when moisture condenses and freezes on the particles of aircraft exhaust fumes. Moisture from the air preferably rains out onto solid materials, such as the fabric of fog catchers.

Condensation alone, however, is not enough to provide water in usable amounts. Once the morning sun starts warming the air again, the absorption capacity of the air rises again. Condensed water starts evaporating. To prevent this from happening, the material has to be taken down and wrung out before sunrise (as a rule of thumb, fog catchers are most efficient just before dawn), or the fog catcher has to be set up in such a way that the condensed water can run off and gather in a collection fold. Dew gathered in small puddles will evaporate much more slowly than when spread out over a large area.

Loose fabrics such as mosquito nets or shade cloths should be hung in double layers, as slight movements by the wind will cause small dew drops to join together and form larger ones. These are less likely to evaporate quickly, will run off to the bottom of the sheet, and are therefore easier to collect.

When it isn't possible to condense water in "visible" amounts—for example, in arid regions—the moist fabric should be packed in an airtight container so that it can be used later in the day to moisten and cool one's clothing (see note in the next section).

The efficiency of fog catchers depends on many factors and is hard to predict. With low nighttime temperatures and high humidity levels, it should be possible to collect one hundred milliliters of water per square meter (2.8 fluid ounces per square yard) overnight.

## Collecting dew

Collecting dew "on the go" presumes that the air humidity has increased by so much that sufficient water has collected on plants, stones, vehicles, and so on. This liquid water is usually

only available for less than an hour in the mornings. After that it evaporates and is lost to us. The early bird catches the worm: You need to get up early and collect the liquid before it's gone.



Even in very dry regions, water will collect on plants near the ground.

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This can be as easy as simply wiping up the dew drops with a piece of cloth. Even backpackers will have a whole range of suitable materials with them, which can be used with varying efficiency. Cotton or linen fabrics, for example, can hold large amounts of liquid but are difficult to extract the mopped-up liquid from. Much better are absorbent man-made fibers such as those used in base layers, or fleece.

A permanent “companion” in my desert kit has proven ideal for this task. For the last ten years, when traveling in warm regions, I have carried a microfiber cloth originally designed for cleaning windows. This cloth allows me not only to “shower”<sup>\*</sup> with half a shot glass of water but also to collect dew in the morning. Microfiber cloths hold large amounts of water, which they easily release when wrung out.

A friend of mine wraps two manmade fiber scarves around his feet and walks around the dewy meadows in the mornings.

Note for warm regions: Once enough water has been collected, and/or the available dew is fast evaporating with rising temperatures, quickly moisten all available clothing for use as a cooling aid in the midday sun.

## Dew in the tent

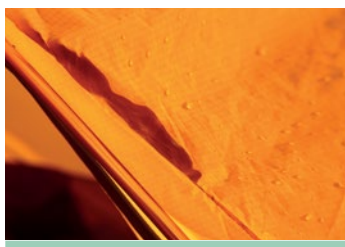
Sleeping in a tent or bivouac sack offers the opportunity to harvest the often large amounts of drinking water from the inside of the outer skin every morning. During the night, the

<sup>\*</sup> Desert shower: Wiping down one's body with a moist cloth. Ideally, you should decide before departure whether the cloth is going to be used for quick washes or drinking water.

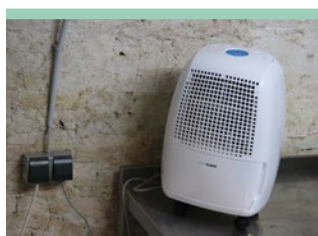
body loses a large amount of water to transpiration and respiration, which will almost entirely condense on the tent walls. In addition, due to the higher humidity inside the tent, moisture from the ambient air will also condense here.

Even in the driest regions, water can be collected, or recycled, in this way, provided the night temperatures are low enough. If the tent isn't aired very well, the moisture content in the air will soon hit saturation level and the water will condense. Moreover, the temperature inside the tent will always be slightly higher than on the tarpaulin, as it is exposed to the ambient air temperature, which facilitates the condensation process.

On the outside of tents you can find condensed fog, too. Here again it is really important to get up as early as possible to save this water. The early morning and the evening generally being the time for physical activity in warmer zones, it is common sense to get up early anyway.



When water is in short supply, the tent skin can be a valuable source of small but potentially life-saving amounts of water. Where cooking equipment and salt or gray water are available, the tent can even be used for distillation.



A professional dehumidifier with a compressor will produce several liters of water from warm air per day. Air dehumidifiers with Peltier heat pumps may be cheaper but are considerably less efficient, as the temperature difference is too small.

## Further condensation methods

**Cooling:** Where functioning cooling or air conditioning appliances are available—for example, in a vehicle or hotel room—it is possible to draw on the liquid created by cooling the air. Indeed, devices have been developed that can be deployed in arid regions for air conditioning and to generate drinking

water. With stationary appliances such as air conditioners, however, it is important to remember that the extracted condensation water is often contaminated with bacteria like legionella, which is why it has to be treated with **reliable treatment methods**.

I have experimented with mobile devices in various deserts, for example, with condensation on **Peltier heat** pumps (cooling elements that are used in ice boxes, for example) or hand-operated cold pumps. All these methods suffer from the fact that they require an enormous energy expenditure to produce a usable amount of water.

You should also keep this in mind when presented with current offers from start-up companies making far-fetched promises. There are different models available (none of which have been built as prototypes yet, let alone produced in noteworthy numbers) claiming to extract drinking water from the ambient air with the use of Peltier elements and a small solar module. Yet this is impossible in the intended manner for physical reasons (the air in sunny regions is too dry, a Peltier element run at low voltages requires a high-ampere current, etc.).

While it is indeed possible to create useful amounts of water by driving around in the desert in a car with the windows open and an open compression cool box set to “freeze” in the back, this is hardly an option with small, mobile, and energy-self-sufficient systems. In arid regions, the ambient temperature is high and relative humidity low. In order to produce a significant amount of water at dew point from condensation, the temperature difference (see table on page 57) must be very large, as must the amount of air put through the device. As a backup (and only with appropriate fuel reserves, as it is a high-energy process), this method can be used to produce several hundred milliliters (several fluid ounces) a day.

In a cheap and easy method, air moisture can be harvested with a stationary and commercially available dehumidifier using Peltier elements, which must, however, be run on power supplied by the electrical grid or a generator. With continuous operation at seventy watts, these units can extract around half a liter a day.



**Hygroscopic means:** Hygroscopic, or water-attracting, materials allow the collection of liquid even at very low humidity levels. **Silica gel** (the small glass-like anti-moisture pellets familiar from synthetic shoes or handbags) is less suitable for this purpose, as it only absorbs a little water. Salts such as sodium chloride, lithium chloride, and calcium chloride from refill packs for air dehumidifiers are much more absorbent. They also have the added advantage that they are much more easily regenerated (i.e., separated from water) after distillation than silica gel.



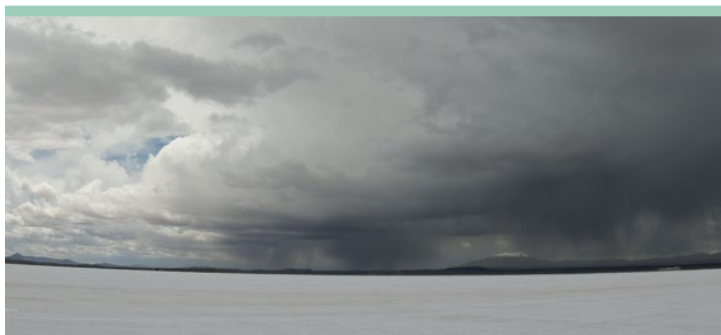
Chemical dehumidifiers first store liquid as crystal water; later it runs off as a distillable alkaline solution. Distilling the crystal water requires temperatures of 392°F (200°C).

## Precipitation

Having talked about water in the air and in the atmosphere, we mustn't forget the moisture that floats in the clouds in the form of snow or ice drops and usually falls onto earth as rain just when we have taken down the holey roof of our emergency shelter to mend it. Only a few things need to be considered when using precipitation as drinking water.

For a start, rainwater is (with almost absolute certainty) always potable without prior treatment, provided

When the sky grows dark and the first rain drops appear, it is time to get ready to collect rainwater.



it wasn't collected in the immediate vicinity of an industrial smokestack (in which case it could possibly contain large amounts of hazardous dust particles) and the precipitating rain cloud doesn't contain radioactive fallout (in which case you'd have bigger problems than just the lack of drinking water).

The effects of acid rain so dreaded in the past decades only become a problem if the rainwater actually reaches the

ground and soaks it through. The incomplete burning of fossil fuels produces emissions with large parts of nitrogen and sulfur oxides, which react with oxygen and water molecules in the air, forming nitric and sulfuric acid. These acids can damage the fine hair roots and leaves of trees and wash metals, heavy metals, and minerals from the ground into the groundwater. For us, however, even "very" acid rain is perfectly safe to drink. The popular carbonated soda pop that we're told to "enjoy," for example, contains much higher levels of acid than acid rain.

In other words, rainwater is practically always potable and one of the safest sources of drinking water anywhere in the world, *provided it hasn't become contaminated after collection—for example, with animal feces*. Large pools of water tend to attract water birds and other animals, which end up polluting the water with germs. Such raw water should go through treatment prior to consumption. Freshly collected rainwater, however, is free of germs (even if not sterile) and can always be drunk as is.

In many arid regions, thanks to the dry and solidified ground, even small amounts of precipitation collect in little



By placing tarpaulin, leaves, bark, etc., at an angle, or by spreading them on the ground, rainfall can be channeled into a vessel. The decisive factor is the area covered, not the shape. On deciduous trees, rain will usually run off along the trunk. A simple fabric tie can channel the water straight into a container.



trickles that combine into torrents. In the event of a one-off precipitation event, it is advisable to visit the terrain structures discussed previously where the combined trickles are sure to pass through. In the lowlands and in the forest, collecting rain with rain catchers can be very effective.

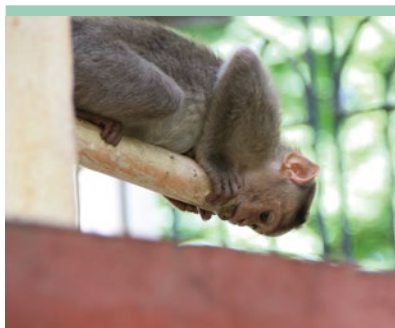
## Cisterns and roof stores

Noteworthy sources of drinking water are roof storage containers or agricultural cisterns, which remain filled with water for some time even in a water outage. Especially in rural areas, there are many of these water cisterns, which only come to use in very dry times and are usually full for most of the year even if not connected. Apart from obtaining permission to use them, you need to consider only one rule before tapping into them: If the water was drinkable without treatment before it was stored, it will remain so for several weeks, provided the tank was locked (keeping out birds, rats, monkeys, etc.) and the contents kept dark.

Liquid obtained from storage containers exposed to light or open to the elements must always be treated. The same obviously applies to water from toilet tanks and similar sources.



Large water storage tanks and cisterns on hills or roofs are usually found in areas where the water supply is unreliable and likely to be interrupted. However, water tanks are often used (and contaminated) by animals. In this case the water must be treated with reliable methods before using it!



## Water from food

Everybody seems to have an opinion on the body's fluid balance, regardless of whether it is based on fact or not. Thanks to endless repetition in books and magazines, veritable dogmas have been created that find many trusting followers—regardless of the truth.

Two commonly repeated beliefs are “If you are short of water, you mustn’t eat,” and “If you are fasting, you must drink lots.” Notwithstanding the fact that both beliefs are diametrically opposed to one another, they completely ignore the physiological realities of the human body. Certainly personal experience comes into this, since fasting makes you hungry and gives you stomach cramps, both of which are alleviated by drinking water, fruit juice, or tea.

In reality, the issue isn't as clear-cut as we might like. Let's start with the belief that we mustn't eat anything when we have run out of water. The argument usually goes that during the digestive process, water is released into the gastrointestinal system in the form of digestive juices. This is indeed the case, but that doesn't mean that that water is then lost to the body: The watery digesta is concentrated again in the later stages of the digestive process, water is removed from the excretions, and the residues eventually contain considerably less water than the original food. As a result, the body's fluid balance is positive, unless the consumed food was dry bread crust.

And yet water *absorption* during digestion is coupled with another, invisible effect. In the digestive process, nutrients are broken down with certain enzymes (hydrolases), and water molecules are then attached, or bound, to the nutrient molecules. So this process needs water.

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**Bon appétit:** There is no need to go hungry, especially with low-calorie foods: Food usually supplies the body with additional water.



Foods with a high carbohydrate content such as bread or pasta lead to heavy “afterburn.” The split sugars and the resulting glycogen are **osmotically active** and need more liquid in the cells to counterbalance the effect. Once the balance has been achieved—for example, with the aid of water contained in fruit or green plant parts—the body’s fluid balance looks healthier again.

As a by-product of “burning” (oxidizing) nutrients, the body produces a fluid called metabolic water. That can be quite a lot: Burning one gram of sugar produces around half a gram of water. One gram of fat even produces a little more than one gram of water.

As a result, eating low-calorie foods means that the body is supplied with more water than is needed to digest them. Plant-based foods are especially good sources of water. Green plant parts are made up of 60 to 95 percent water; the rest is dietary fiber and minimal amounts of sugar and fat. The water is absorbed, and the fiber is excreted in a water-efficient manner. The great advantage for us lies in the fact that plants (unless they have been contaminated from the outside) don’t harbor any harmful **pathogens** on the inside, which is why they can serve as a source of drinking water even in regions with heavily contaminated surface waters. On the other hand, certain environmental toxins such as mercury, cadmium, and lead or radioactive isotopes do build up in plants, which is why plants from ground polluted by industry or floods should not be consumed without prior distillation.

All green edible plants that are not **diuretic** are suitable to eat directly. It is therefore possible to obtain water even in arid regions where it hardly ever rains.

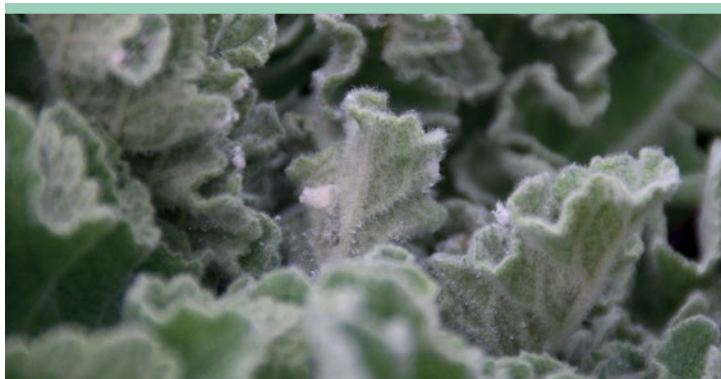
When eating only green plant parts or lean meat, the resulting slow weight loss will have another side effect: Any water stored in fatty deposits, muscle tissue, and glycogen stores is released when these tissues are broken down for energy. This means the body can access *between a quarter and half a liter* of metabolic water each day. That may not be much, but in a water shortage it will be enough to noticeably reduce the daily water requirement.

## Water from plants

You will probably know that plants take in water and nutrients through their roots. Yet roots are much more delicate than they may seem when you look at a plant pulled out of the ground. Microscopically small root hairs are able to draw even the last hint of moisture out of dry sand.

Some plants are covered in a reflective felt coating to protect themselves against direct sunlight and excessive evaporation.

In arid regions, roots can grow several meters deep into the ground, reaching moist layers or spinning an extensive web to reach the vital water.



## Transpiration

It is easy to think that compared with mammals, plants only need very little water, but that's actually not the case. In fact, in relation to their own weight, plants need many times more water than mammals of the same weight would need to drink. Almost all of the absorbed water is released by plants through their leaves. They “transpire,” but unlike humans they don’t sweat fluid (although some mangroves can “sweat” salt crystals) but release water molecules as vapor into the air. This occurs in various ways. A plant loses small amounts of water on the surfaces of its cells; much more, however, diffuses as water vapor through tiny sealable pores called stomata during carbon dioxide absorption. And that’s exactly where the plant’s problems begin (and therefore ours, too.)

Water diffused through the leaves condensing on the inside of a plastic bag.



In order for a plant to produce sugar with sunlight, it needs to “breathe,” or open its stomata. If this happens during the day, it loses a particularly large amount of water. As a consequence, plants have evolved to adapt in different ways.

In warm regions, many plants have a **xeromorphic** adaptation, where the leaf surface is sealed with an impermeable waxy coating or has light-reflective and insulating hairs, or, to reduce evaporation, particularly thick leaves (one extreme form of fleshy leaves can be observed in cacti).

In contrast to plants in moderate climates, many xeromorphic plants don’t respire during the day but at night, when they lose less water at the lower temperatures.

That ability to store carbon dioxide in the cool dark of the night and to use it the following day during photosynthesis poses a particular problem for us. These **C<sub>4</sub> plants** (many grasses) and **CAM plants** (cacti, for example, and many others) tend to grow between the thirtieth parallel and the equator. **C<sub>3</sub> plants** (most of the plants in temperate zones)—i.e., plants that respire and transpire during the day—tend to grow more in colder regions where water emergencies are less likely.

A mature tree can easily emit 500 liters (150 gallons) of water per day through transpiration. But without the experience and means of a wrapping artist like Christo, covering an entire tree in plastic foil is unlikely to be a realistic option. But even trash bags, tarpaulin, or condoms can come in handy: Wrap as much foliage of an undamaged plant as possible and seal it airtight. Take care not to use any species

with waxy, dusty, silver-haired, or leathery leaves, as they indicate xeromorphic plants. Plants that prefer to grow in the shade usually don't have special protection against heat. Their main problem is not with water uptake but with the lack of sunlight.

A further influencing factor is the temperature around the leaves. At around 95°F (35°C), the stomata on plant leaves close, reducing evaporation to a minimum. Either you use the technique in the shade or under the blazing sun. At very high temperatures, like those created inside a plastic bag, the water inside the leaves evaporates even with the stomata closed. The bag around the leaves must contain enough air but must also be sealed as tightly as possible. Note that the higher the humidity inside the bag, the less water the plant will release. After just a few minutes, the first few drops of condensation will gather in the bag, which will quickly collect at the bottom after a little shake of the bag. As long as the leaves are undamaged, even very poisonous plants will not release any noteworthy amounts of active substances (apart from essential oils) into the air.

This fairly sizeable effort for relatively little water is only worthwhile when you are unsure if a given plant is edible, and distillation is either not possible or too much effort. If the plant is known to be edible, use a different method: Extract the water from the leaves, or simply eat them.

### **Extraction**

With succulent, edible plants, usable drinking water can be extracted very easily. Depending on their consistency, the plant parts are either cut up or squashed, put into a pan and heated slowly. It is helpful in the beginning to press the material against the bottom of the hot pan. After a short while, the cells will burst and the liquid released. As soon as a thin layer covers the bottom, put the lid on the pan and reduce the heat. Induced by the hot steam, all the remaining plant parts will now release their water, which collects at the bottom. Once cooled, it can be drunk straightaway.





In deserts and semideserts, prickly pear and agave are typical drinking water resources. Prickly pear leaves can be peeled and eaten straightaway. CAM plants such as prickly pear release practically no water at all into the atmosphere during the day, and their thick, waxy leaves prevent them from losing much liquid. Most cacti are edible, so liquid can be obtained by extraction or consumption. With slightly poisonous plants such as agaves, liquid should be obtained through distillation.

### Simple collection

Often liquid water can be collected several days after the last rainfall from plants with expansive foliage or bowl-shaped structures. A particularly impressive example of this is the ravenala, also known as traveler's tree, from Madagascar, which stores large amounts of rainwater. Cavities in *Strelitzia* or banana trees, bamboo cuttings, tree holes, and tree trunks will also harbor water for several days after the last rainfall.

Another well-known method of obtaining water from plants is by cutting into the bark of a tree. With birches and sugar maple, the process is exploited on an industrial scale. Yet it can be done on practically any tree that you know is not poisonous.



Cut up pieces of edible plants are heated up until the heat squeezes the water out, just like a steam juicer.

One exception are conifers: Their vascular tissue contains veritable one-way valves as well as resin ducts that prevent the juice from escaping. Remember that the fluid flow tends to be strongest during the spring months. Later in the year, transpiration on the leaves creates a strong vacuum inside a tree. In this case, the bark needs to be cut a little above the ground and then again extensively directly above that cut, as high on the tree as possible, in order to release any liquid at all.

**Note:** Unidentified vines and other potentially poisonous plants should never be used as drinking water sources. Rules of thumb like the one claiming that clear juice from vines is always potable can quickly lead to fatal poisonings. The only decisive factor is that *you know the plant to be safe*. If you are at all unsure, use the plant material for distillation or collect the water vapor from the plant's transpiration.

## Water from animals

In the past, rumor circulated that fishermen were able to survive at sea for weeks thanks to the liquids squeezed from animals. In order to assess the verity of this statement, you need more information, since you surely know (or at least will learn in the course of reading this book) that you must



Water from cavities in plants should be treated prior to consumption, as it is likely to be contaminated with insect or bird feces.

never drink salt water. Why would drinking the juices of sea animals be any less dangerous? What is important

for us to know in this context is the makeup of bodily fluids, especially blood. An important factor in this is **osmolarity** (see “Sodium chloride (table salt),” pages 107–12) along with its electrolyte or salt content. If it is too high, we will “lose” fluid over a period of time, as the ingested salts need to be removed from our body. If it is lower or the same as our osmolarity, we can safely drink the liquid over a long period of time.

Fundamentally, there are two types of animals: Those that control the amount of salt in their bodies—the “osmoregulators”—and those that adapt to the salt content of their ambient medium, the “osmoconformers.” Fluids extracted from virtually all osmoregulators can be consumed instead of drinking water and have a **positive fluid balance** effect on us. Fluids from salt water–dwelling osmoconformers, however, have the same salt content as the ambient seawater (see “Salinity levels of different bodies of water” on page 111).

Virtually all vertebrates except sharks are osmoregulators, with a blood makeup very similar to ours. This group includes birds, land mammals, and freshwater and saltwater fish. The latter are able to excrete any excess electrolytes via special glands.

The group of saltwater osmoconformers that cannot be used as a source of drinking water includes—besides sharks—virtually all species of invertebrates, including mollusks such as snails and bivalves but also jellyfish and the like.

As discussed previously, the body uses water to break down certain proteins and carbohydrates from bodily fluids and blood. If you have to rely on the juices of osmoregulators for drinking water for an extended period of time, the

proteins at least can be removed very easily with heat **precipitation**. At very high temperatures, many proteins denature and are no longer water soluble.

The liquor on top of heated “animal juice” contains only a small amount of the hard-to-separate, dissolved salts and relatively little sugar and fat. The liquor can therefore be considered adequate drinking water.

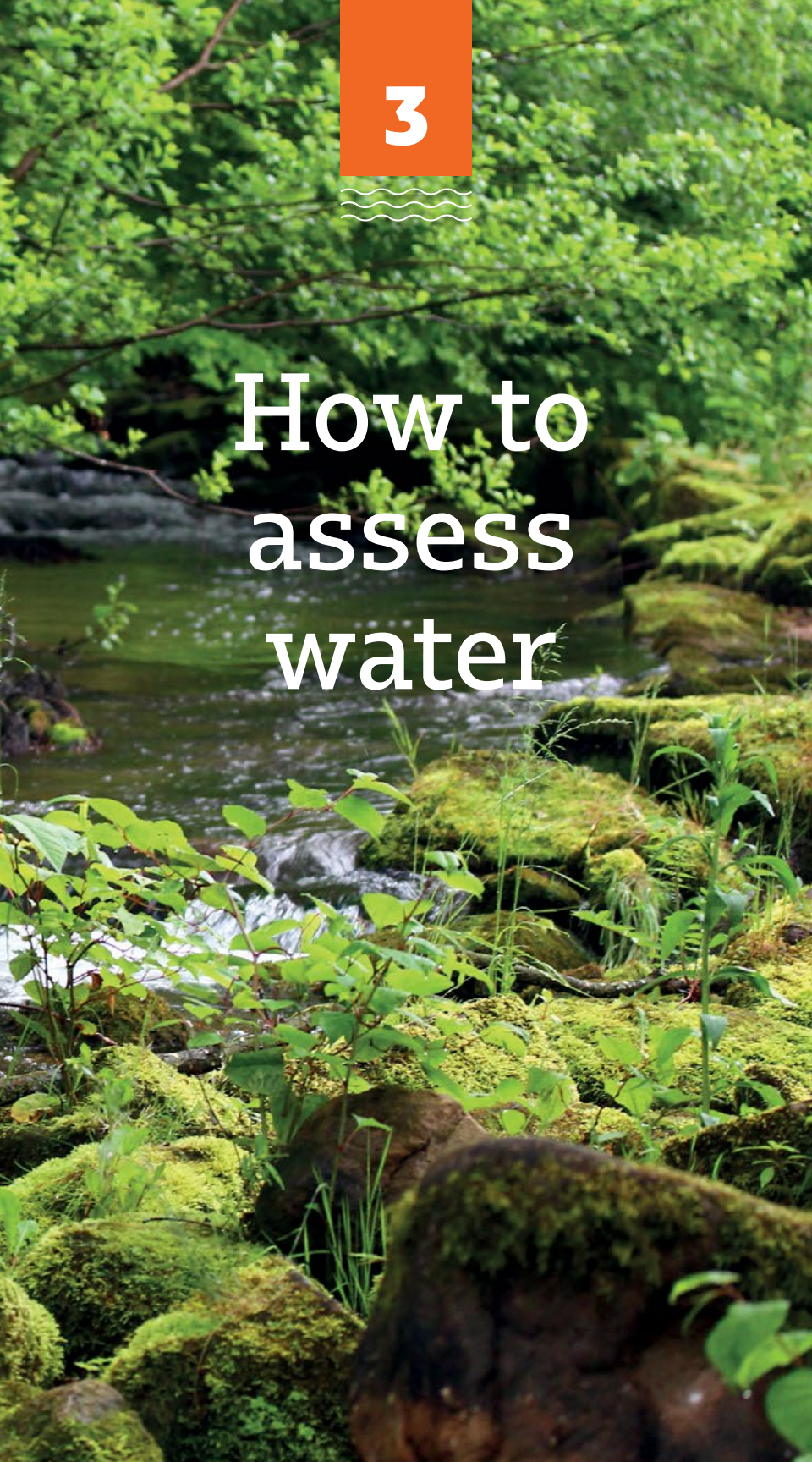


Juices squeezed from a freshwater fish: The left sample shows a liquid with suspended proteins. To completely remove the proteins, heat the liquid until the proteins precipitate and sediment. The water can then be decanted and filtered.







A vertical photograph of a forest stream. The water flows over dark, moss-covered rocks. The surrounding forest is dense with green foliage. In the foreground, there are more mossy rocks and some green plants. The overall scene is vibrant and natural.

3



# How to assess water



# How to assess water

**W**hen you find water in the open countryside—called “raw water” after collection and before treatment—it is rarely sterile or totally toxic; usually its “quality” (not in the sense of value) is somewhere in the middle. Your task is to recognize the type and degree of pollution.

Once you have established this, you can start the specific purification process. Of course, you could always apply every possible treatment method as a precaution, but after learning about each method explained here you will soon realize that the effort would be absurd.

We assume that you will only have the usual trekking equipment as well as natural and/or improvised, and therefore finite, resources available, and that you will treat water as much as necessary but also as little as possible. The aim is, on the one hand, to save energy and resources—you need a considerable amount of water every day, the effort adds up—and, on the other hand, to prevent further contamination of the raw water caused by inappropriate treatment.

The following questions must be asked when initially assessing raw water quality:

- Has the water been contaminated by *significant* amounts of industrial or agricultural wastewater? (A single mountain goat leaving its droppings in a stream can be ignored just as safely as a lone chancer panning for gold in the Yukon River. The situation is entirely different with open drainage channels.)



- Are fertilizers and pesticides washed into the river from adjoining agricultural land?
- Are human waste and feces released into the water untreated?
- Are there any natural contaminants or parasites in the water?

In order to demonstrate the manifold possibilities of the different types of water sources one might encounter, we'll have a look at a few examples.

**Example A:** A small, babbling brook, its water quite cold, and the current faster than walking speed. Occasionally, large stones and rocks disrupt the flow, churning the water and triggering eddies. There is little or no vegetation on the banks. The bottom along the outside bank of a bend consists of fine sand. There are few or no muddy deposits in the small back eddies behind rocks along the bank.

**Example B:** A natural stream, wide and slow flowing, but still winding. Vegetation fallen in from the banks gathers in the outside bends. Stirring the water here produces a slightly foul odor. Stone surfaces are covered with a slimy film of **algae**. The bottom, though more heavily covered with vegetation, is clearly visible. The water is clear but cloudier than in mountain brooks. When you sink your feet into the bottom, small bubbles that smell of sulfur rise to the surface.



The clear water in this open channel comes straight from a large sewage treatment plant. Water samples used during the purification tests described later were taken from this site.

**Example C:** A deep and calm river, its course straight or canalized, the water muddy and murky. The fingers of an arm dipped in up to the elbow are no longer clearly visible. The water has a foul odor; given the population density, we can assume that sewage, wastewater, and fertilizers are being dumped into the river.

**Example D:** A body of water without a perceivable current. Its banks are covered with a green, slimy biofilm. There is very low visibility through the surface. The water has a foul smell, and no animals are visible. The water is warm and streaked with slimy strings of algae or covered with a thin film of algae. The pond or lake is “dead.”

**Example E:** Small pools or ponds, heavily polluted with chemical and agricultural wastewater. The water has a distinct discoloration; it appears entirely lifeless, but stones are covered with what looks like a layer of gray or whitish “cotton.” The water smells of fuel or other chemical. Streaks of organic contaminants such as oil or gasoline give the surface an opalescent shimmer.

When assessing water to understand if it is drinkable (or can be made drinkable), we need to look separately at certain *properties of raw water* on its own as well as *properties of a body of water*.

## Properties of raw water

### Turbidity

A property of raw water that is easily recognizable at a glance is its turbidity (cloudiness), but it is one that is surprisingly difficult to quantify without further examination.

Small organisms breeding in water disperse evenly by beating their flagellum, sink to the bottom, or float under the surface. Individual bacteria, amoeba, paramecia, and other protozoa (single-celled organisms) are invisible to the naked eye, but collectively they appear as an opaque haze.

In moving water, the water layers obviously mix more

evenly than in ponds. In the latter, the highest concentration of germs is found in the first few oxygen-rich, sun-drenched meters under the surface. The deeper you go for drawing water, the less murky it is likely to be—and the lower the number of harmful germs.

***Although a high concentration of pathogens manifests itself as cloudiness, severe cloudiness in itself is not necessarily an indicator of high microbial contamination:*** Turbidity is also affected by swirled-up sediment such as mud or sand. Still, it is an important parameter for the nutrient content of water; some purification methods are also affected by high turbidity.

When taking water from a river, keep the container still for a few minutes before establishing the level of turbidity to allow heavy particles such as small plant parts and sediment to sink to the bottom.

For technical water treatment purposes, turbidity is measured in nephelometric turbidity units (NTUs), or Formazin turbidity units (FTUs). Liquids are compared to a standard solution with a synthetic material called Formazin using a special device called a nephelometer. Since we have to rely on our eyes only, we work with approximate values.

According to the National Primary Drinking Water Regulations, the maximum limit for drinking water in the US is 1 NTU. Apart from the fact that such turbidity isn't even noticeable with the naked eye, the value says nothing about water quality, given that a turbidity of 0.5 NTU caused by cryptosporidia will certainly lead to serious illness, while a clay solution of 100 NTU is perfectly harmless.

Yet high natural opacity matters because water to be disinfected using UV light should be no more than "slightly cloudy," and trekking filters used with "moderately cloudy" water tend to clog after just a few liters. For us, turbidity is therefore mainly a parameter that determines whether pre-treatment methods such as sedimentation, prefiltration, or heat precipitation need to be applied to the raw water before other purification methods.

We distinguish just four types of cloudiness here, which I suggest you recreate at home with water and whole milk to practice on:

- **Without visible cloudiness** (equivalent to pure tap water)
- **Slightly cloudy** (ca. 50 NTU): Looking through the vessel (clear bottle, water glass, or similar, around 3 to 4 inches [7 to 10 centimeters] in diameter), the back of a knife (1.5 mm wide) is still clearly recognizable (equivalent to five to ten drops of milk per 200 milliliters of tap water).
- **Moderately cloudy** (100 to 200 NTU): The back of a knife (1.5 mm) is only barely recognizable through the vessel (equivalent to eleven to fifteen drops of milk per 200 milliliters of tap water).
- **Very cloudy** (over 200 NTU): Visibility through the vessel is severely limited; you can no longer look through the vessel (equivalent to thirty drops of milk per 200 milliliters of tap water).



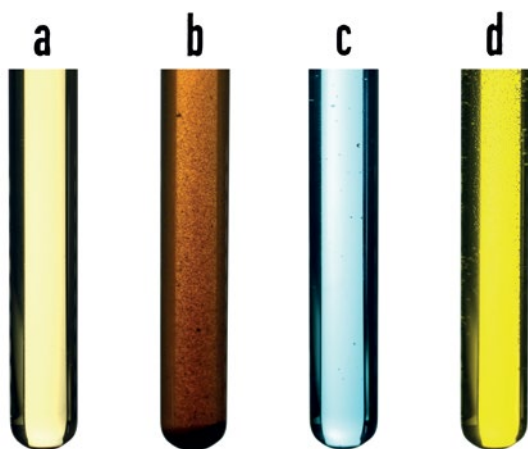
The turbidity levels important for our purposes are easily distinguished.

## Discoloration

In contrast to turbidity—which indicates the presence of particulates, or a **colloid**—discoloration stems from dissolved substances, or solutes, in the water. Chemicals dissolved in water are practically invisible, not even discernible by microscope. If anything, they only change the color of the water. The same applies to substances released by decomposing algae in **eutrophic**, or nutrient-rich and plant-dense, waters. Recognizing and removing solutes from water is far more difficult than removing particles from cloudy liquids.

Some of the substances affecting discoloration are partly derived from organic sources, and others from minerals and metals. Decomposing leaves, wood, or peat in the water, for example, release large amounts of tannins, giving rivers in the tropics or ponds near moors the appearance of black tea. Even clean spring water may have such a tan, brown, or black coloring when mineral solutes such as **iron** or manganese are present in the water.

Bright or even strident discoloration, however, usually points to an unnatural contamination with industrial wastewater. Bright yellow, neon green, or blue are often indicators of highly concentrated chrome, lead, or copper solutions



While tannins (a, drinking water from a freshwater lens on the German island of Norderney) are harmless, a more severe discoloration (b, iron compounds) or unnatural colors such as cyan (c, copper) or neon yellow (d, chrome) indicate a potentially harmful concentration of solutes.

released by chemical processing plants or the mining industry. Water from such brightly colored sources should never be used as drinking water without very thorough treatment and purification. Apart from distillation and reverse osmosis, it is impossible to separate large amounts of solute metals in the field.

Besides helping us to spot the potential presence of industrial contamination with heavy metals, discoloration is also of concern as it, too, limits the effectiveness of certain treatment processes. Humin-rich water (containing the soluble chemical compound of humus), for example, should not be treated with MOS (mixed oxidant solution) or hypochlorites, and charcoal filters can quickly become saturated with the solutes, leading to a contamination of the drinking water with the substances retained in the filter.

We distinguish the following water discoloration grades:

| Discoloration level                                           | Assessment*                                                                                                                                                                                                               |
|---------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>No discoloration</b>                                       | Harmless                                                                                                                                                                                                                  |
| <b>Slight natural discoloration</b> (like weak chamomile tea) | If tannins are the suspected cause (peaty ground, tropics), no special treatment necessary; otherwise apply oxygen precipitation before filtering.                                                                        |
| <b>Dark, natural discoloration</b> (like black tea)           | Especially in (former) mining regions, must test for iron and manganese by applying oxygen precipitation. In the absence of neither, taste test for tannins or bitter compounds. <i>If not bitter, distill the water.</i> |
| <b>Neon yellow, green, blue</b>                               | <i>Avoid using if possible!</i> Contamination with heavy metals to be suspected. In the absence of an alternative source, distill the water, ideally several times.                                                       |

\* But please note: Water should not be assessed purely on its odor and taste. Other indicators such as turbidity and discoloration should be taken into consideration.

Unlike cloudiness, the source of discoloration is a dissolved substance that can't be separated from the water by simple filtration or sedimentation. Organic coloring can be temporarily reduced with a carbon filter; inorganic discoloration—i.e., from solute minerals—can be separated to a certain degree with precipitation or potentially through reverse osmosis or distillation.

## Sensory assessment

Besides measuring raw water properties with equipment, it is important to assess water quality with our senses. Humans are equipped with highly sensitive measuring abilities. Smell and taste are particularly important senses when testing water for potability.

In fact, assessing whether food and drink are fit for consumption is the main purpose of the nose and tongue. We may be pleased to detect subtle perfume notes instead of strong body odor on another person, and we may delight in delicately seasoned foods, but the most important question that our smell receptors and taste buds have to answer is “Edible or poisonous?” This instinctive assessment system is still present in *Homo urbanus*—even if sometimes badly distracted or tricked. We can still tell if (unseasoned) food has gone bad by its odor and taste.

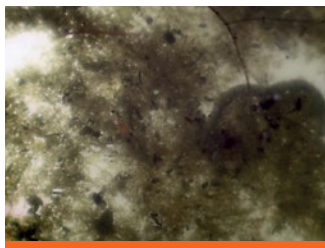
Even dissolved in water, we can detect tiny amounts of hydrogen sulfide by their smell. And we even have a whole sense of taste dedicated to the detection of salt water (see “Determining salinity” on page 112). But the vast majority of poisonous or harmful substances are not detected in time, and humans certainly can’t identify any parasites or pathogens in this manner.

It is therefore important to take sensory assessment as a *point of reference*, not as a *safe indicator*, especially given that sensory tests literally depend on one’s subjective “taste.” Smokers, for example, have a much more reduced sense of smell than trained wine makers, and while some people may enjoy a bitter dish, it can make others retch.

Ideally, water should be tasteless and have a neutral odor. With the exception of spring water, however, practically all natural water sources have their individual odor and taste. Even water in a stream smells and tastes slightly musty just a few hundred meters below its source. Try to familiarize yourself with this *natural* property of surface water, as it is normal and harmless. For example, collect a few liters (half a gallon or so) of water from your nearest large river and from a small



Nearly all surface waters contain near-invisible algae, dead plants, and microorganisms as well as their excretions.



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clean stream and boil the different samples at home.*

After it's cooled, stir in some air (boiled water is poor in oxygen, which affects the taste a little) and compare the taste. With both samples, you will notice that natural water has an unusual taste—certainly not as neutral as tap water.

In surface waters, nutrients accumulate naturally: Insects, leaves, mosses, and so on fall in, sink to the bottom, and decompose into **detritus**. Excretions from bacteria and other microorganisms processing the detritus are dissolved in the water and absorbed by algae as food. The sensory properties of this “clean river water” therefore represent a harmless mélange of all these organic substances. The further we move away from the source, the more these compounds add up—and that comes through in the odor and taste. (The origins of this natural taste are explained in more detail in the section on the saprobic index, page 120).

Of course, the intensity of the individual flavor of a body of water depends heavily on its surroundings. Water traveling above the tree line tastes less intense than sludge from an estuary. Using your senses therefore allows you to estimate how far you are from the spring, and—this is especially important for us—if there is a potential sewage inlet upstream of the collection point. Below a sewage inlet, the trophic index of a body of water soars (see also pages 124–25). The ensuing increase in nutrients and decrease in oxygen produce a strong “boggy” taste. A particularly foul odor is a sure sign that the water needs to be treated with reliable methods before consumption.

* Before you collect water from any river to experiment with, ensure potential health hazards are not present—in particular, from major industrial sites where heavy manufacturing, mining, or waste disposal either has occurred or continues to occur.

Furthermore, a simple smell test can be carried out in a calm area of a body of water. Using a stick, stir the water while taking care not to disturb the bottom. An emanating odor of rotten eggs suggests anaerobic decomposition (decay) of the nutrients: Compared to the oxygen content, there are too many nutrients to decompose naturally. This may be caused by an inlet of untreated sewage or by nutrients entering from the banks. We obviously don't want to take any risks with this, so we distinguish the following:

Odor	Taste	Assessment*
Neutral	None or slight river flavor	Potable without treatment
Slightly pond-ish	Intense river flavor	Simple germ reduction required
Foul	<i>DON'T TASTE!</i>	Reliable treatment methods required

* But also take other indicators such as turbidity and discoloration into consideration.

Of course, you shouldn't taste raw water from rivers you suspect to be heavily contaminated without boiling it first. But sampling even small amounts of boiled water will give you an idea if and how intensely the water needs to be treated.

Raw water vs. drinking water

Water is not the same as drinking water (we established this fact in the chapter about the physiological effect of water in the human body). According to the current guidelines issued by the World Health Organization (WHO), safe drinking water must "not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages." It further states that the provision of drinking water that is "acceptable in appearance, taste, and odor" is of high priority.

This description may have subjective components (for example, taste), which in the field may be discerned with only freshly collected spring or rainwater, but it shows the requirement and how it may help us infer how best to treat

raw water in order to obtain drinking water.

Let's start with the premise that drinking water must not "represent a significant risk to health." A major risk factor in drinking water is waterborne diseases, caused by a variety of harmful pathogens; any kind of microorganism—such as a virus, bacteria, fungus, algae, or larvae—that can cause a disease. They are harmful because they can use the human body as a host in order to multiply, feed off, or repro-

duce, causing harm to one's body in the process. The most decisive factor is a person's own physical disposition and condition; one's overall health ultimately decides whether a certain pathogen will lead to an infection or poisoning of the body.

While the human body is capable of killing many pathogens and deactivating selected poisons with its immune system, certain disease-causing pathogens have developed strategies to fool our bodies. Moreover, in a weakened immune system (for example, caused by a change in climate, jet lag, illness, or even dehydration), there are microorganisms capable of making a person ill even if they don't normally cause diseases. They take advantage of the weakened body, which is why they are called **facultative pathogens**. Furthermore, whether a germ is pathogenic or not can also depend on its developmental stage, as is the case with liver flukes and tapeworms. Another factor is the location of where the pathogen attacks. **Fecal germs** live in enormous numbers inside the human gut, but just a fraction of them entering the upper digestive system can lead to an infection or poisoning.



Wherever humans use a body of water in any way, fecal contamination through agriculture or canalization is to be expected.

Apart from pathogens, various solute “toxins” are also relevant to us. Harmful substances are present in *any* water (except for ultrapure laboratory water). Even clean tap water contains lead, cadmium, uranium, pesticides, aromatic hydrocarbons, and other toxins. Water is a good solvent. What determines fitness for consumption is *purely* the amount, or concentration, of the individual particles in relation to their toxicity. The WHO guidelines provide strict limits for all of them, below which the ongoing consumption of these substances presumably does not cause any physical harm, according to the *current state of research*.

In emergencies, or even over a period of several weeks, we can safely ignore many of these limits—especially since they are impossible to achieve in the wild. With some, however, it is exceedingly important that we adhere to them.

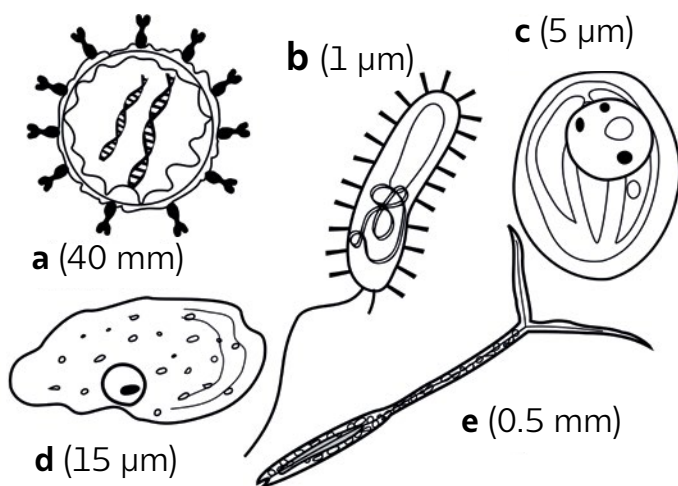
For a better understanding, we will explore potentially dangerous components of raw water and their distinguishing characteristics in the following sections.

Pathogens

Viruses

Dirty water can contain several types of viruses—extremely small pathogens that don’t have a metabolism of their own and are therefore not always considered living organisms. This means that viruses have to invade a host in order to reproduce. The contagion occurs through free viruses or infected host cells that are inhaled or ingested or that enter the body through open wounds. Inside the body, they infect human cells and transfer their virus DNA.

Inside the host cells, the viruses’ genetic material is replicated; this enables *the host* to produce the new viruses. Once a certain number of viruses have been created, the cell bursts, and the viruses are released into the body where they attack new cells to multiply, and so on. Most viruses are “loyal” and rarely jump species, but there are some that move between different species of mammals and are therefore able to transfer diseases from animals to humans.



Important pathogens that can cause waterborne diseases (various magnifications): Viruses (a; here a norovirus with a diameter of just forty nanometers) are a hundred times smaller than bacteria (b; *Vibrio cholerae*). The most important pathogens, however, are bigger than one micrometer: infectious stage of cryptosporidium (c), an entamoeba (d), and a cercaria (e).

Due to their small size (in nanometers), it takes complex technical methods to filter free viruses out of water. There are now filters on the market that, thanks to various pre-filter stages, allow for a high level of filtration to remove viruses among others. It is worth noting, though, that many manufacturers' claims are not worth the paper they're written on: The popular filter size of 0.1 micrometer equals 100 nanometers, while most infectious viruses are actually much smaller than that. The fact that filtered drinking water rarely causes viral infections is down to other factors.

Outside their host cell, viruses can only survive for a limited time; the concentration of free viruses in water is therefore fairly small, while a single mucosal cell from the intestines of a mammal may contain hundreds of thousands. Most mechanical water purification methods therefore ignore free viruses and remove the cells, and thus the large number of infective viruses contained in them. To fight viruses effectively, all animal, plant, and bacterial cells must, therefore, be removed from the water. In order to eliminate the relatively small number of free (and often no longer infective) viruses in the water,

you can apply methods that use UV light or **oxidizing substances** that damage the viral DNA or their protein coat.

There are a few very harmful and infective viruses that can be transmitted through poorly treated drinking water and lead to serious infections. Here we will look at two important examples of **human pathogenic** viruses, the rotavirus and hepatitis A, and will also look at a particular kind of virus that “feeds” on bacteria.

Rotaviruses

Rotaviruses are considered to be the most common cause of viral diarrheal disease. Every year, more than 750,000 people die from the consequences of diarrhea caused by these viruses: dehydration and **exsiccosis**. Rotaviruses are most commonly transmitted through drinking water contaminated with feces and insufficiently heated food. In the gut, they attack cells and release a toxin. The afflicted digestive tract then tries to reduce the viral burden by flushing out the infected cells.

The classic symptoms are an internal drying out caused by severe watery diarrhea and vomiting. The infection can last several days, during which the gut is barely able to absorb water, making the infection life-threatening within a short period of time. Children, the elderly, and other weakened people are especially at risk. Another big problem is that if a rotavirus infection in the field is not diagnosed as such, it can be made worse by administering antidiarrheal agents, which effectively prevent the toxins from exiting the body.

With continual administration of clean drinking water and food (even if it is not kept down), the illness usually resolves itself within five to seven days. During the illness as well as for several weeks afterwards, the patient excretes the virus in their feces, so extra precautions must be taken during their care. Apart from prior immunization, there is currently no effective treatment available for the disease.

Hepatitis A

Hepatitis A is another disease transmitted through fecally contaminated drinking water, direct or indirect contact, or

inadequately prepared food. The **incubation period** is roughly two to three weeks, but in some cases it can be several months, making the actual source of the infection difficult to identify. The acute phase of the illness can last many months.

In contrast to rotaviruses, the hepatitis A virus (HAV) also infects the liver. This inhibits the organ from processing certain waste products of the body, which can lead to jaundice. Usually, a hepatitis A infection passes without severe complications, but it can be serious if the patient's general state of health is already weakened.

Unlike hepatitis B or C, which are transmitted through blood transfusions or unprotected sex, hepatitis A always resolves completely and without permanent damage. Vaccinations are available for hepatitis A and B, which is recommended for travelers in at-risk destinations.

Assessing the danger posed by viruses in raw water

With rotaviruses, hepatitis A, and many other viral infections, once the disease has taken hold, it is no longer possible to effectively fight the actual pathogen. During the acute phase, all you can do is treat the symptoms and stabilize the patient's condition.

Virus-related dehydration must always be balanced by the administration of more clean water: With many viral infections, dehydration considerably weakens the body's immune system and renders it too weak to be relied on as the sole healing method.

The only real protection against certain viruses is active immunization—i.e., vaccination—as well as avoiding contact. Since outside of their host cells viruses are very instable and usually only occur in such small concentrations that infection is unlikely, it usually suffices to remove all potential host cells from the water.

Treatment methods designed to remove or destroy bacteria will in all probability also eliminate all harmful viruses.

Bacteriophages

A variety of viruses occurring in significant quantities in raw water, bacteriophages deserve their own mention here. As discussed above, viruses tend to have a very limited range of hosts. Phages are viruses that attack, infect, and destroy bacteria. In fact, they are so efficient at this that they are able to significantly reduce a specific bacterial concentration within a few hours. It is assumed that globally, half of all bacteria are killed by phages every few days. (As most bacteria regrow just as quickly, however, there is no need to put the germs on a conservation program just yet.)

Every milliliter of raw water can contain many millions of phages. They can drastically decimate the bacteria in fecally contaminated water. This was discovered by observing the effect of wastewater from the Ganges (water with very high phage content) on the usually fatal disease of cholera.

We still know relatively little about the medical benefit of phages, since science has historically focused on antibiotics instead. The latter having served medicine with great effect for nearly a century, their overuse is now causing resistance problems and forcing scientists to turn their attention to phages again.

We can take as a given that every liter of water contaminated with any bacteria also contains a certain number of phages. Before applying unreliable filtration methods such as **germ count reduction**, water very clouded with bacteria should therefore (if possible) be stored in a container in the shade for a day. By the time the water has been clarified by sedimenting and decanting, phage activity may well have reduced the bacterial count considerably.

Bacteria

In the field, it can be quite difficult to test water to a great degree of accuracy. In the laboratory—under sterile conditions—microbiologists testing substances for bacterial contamination use a variety of cultures to exclude or confirm certain species, allowing them to determine the actual

presence and number of different bacteria (this is also how I examined the various treatment methods described in this book). In an emergency, it is unlikely you'll have access to the necessary equipment. It is therefore important to treat any kind of bacterial contamination as undesirable—and potentially harmful—and try to reduce or remove it entirely.

Practically all water sources, including ground, tap, and well water, contain various kinds of bacteria, but not all bacteria are automatically harmful or human pathogenic.

Even without the use of a laboratory, we must of course assess whether there are some microorganisms present that have unpleasant consequences for us, or if the water can be consumed safely. For that we look to the WHO's *Guidelines for Drinking Water Quality*, which state that no "coliform bacteria" must be detectable in any one-hundred-milliliter sample. What does that mean?

Coliform, or fecal coliform, pathogens are bacteria with a metabolic activity similar to that of the most important bacteria in the intestine of mammals: *Escherichia coli*, or *E. coli* for short. Well adapted to the available food and temperature, they are able to live inside the human body.

We are constantly ingesting small quantities of these germs (even with good personal hygiene), usually without any ill effect at such low concentrations. As long as we don't literally drink liquid manure, a small amount of *E. coli* is unlikely to cause harm, even in drinking water.

So why the strict limit of the WHO's guidelines that not a single bacterium from this group should be detectable in drinking water? The answer is simple: If a drinking water analysis shows that there are natural gut bacteria present in the water, it indicates that the source is *fecal contamination*. And where there are gut bacteria from mammals in the water, contamination with other, more dangerous pathogens is likely to have occurred, too.

The following factors affect the danger posed by contaminated water:

1. The safe limit of pathogens is highly dependent on the strength of a person's individual immune system and their habitual exposure.
2. Ingesting a very large quantity of slightly harmful pathogens can nevertheless lead to an infection or the outbreak of a disease.
3. The maximum tolerable quantity of pathogenic organisms is considerably lower than that of facultative pathogens (those that do not cause harm if the host organism is in a healthy condition) or **nonpathogenic** organisms (those that do not cause harm).
4. A person's health can be affected by toxins produced by bacteria even in the absence of "active" pathogens.
5. Some pathogens are so adapted to the human body that only very few individual organisms are necessary to cause an infection. Contagion can only be prevented under laboratory conditions.
6. Infections caused by highly pathogenic organisms can be transmitted by inhaling one single aerosol droplet and are impossible to avoid even with the adoption of all possible hygiene measures.

For that reason, all water purification methods are nonspecific and instead kill, reduce, or deactivate all microorganisms—even if they are harmless. Since improvised methods don't allow for a total separation of all bacteria, we want to reduce their number at least by so much that ingesting them has no unpleasant consequences.

Many people today tend to suppress the thought that we are constantly picking up relatively large numbers of pathogens, fecal germs, and other microorganisms. But the truth is that many thousands of germs enter our body every day, be it through inhaling aerosols in the air from someone else's

sneezes, eating food, or even simply breathing. With *slightly harmful* bacteria, our body can easily cope with several hundreds of thousands of germs. With *very harmful* bacteria, however, as few as a dozen may be enough to cause an illness.

Below we will look at a number of examples of bacteria-related waterborne diseases.

Cholera (*Vibrio cholerae*/El Tor)

Cholera is a widespread disease occurring mainly in South America but also in many developing countries on other continents. A cholera infection is nearly always the result of eating food or drinking water contaminated with human excretions. Although the number of organisms necessary to cause an outbreak of the disease is relatively large, the infection is prevalent globally. This is because patients suffer from severe diarrhea caused by toxins released by the cholera bacteria. Without proper sanitation, enormous numbers of the pathogens are dispersed into the environment.

It is exactly these symptoms, so typical of waterborne diseases, that make cholera so dangerous: The absorption of water in the gut is inhibited to such an extent that a patient can excrete up to twenty liters (five gallons) of fluid per day, which without treatment and adequate preservation of fluid balance (for example, with infusions) will lead to the patient's death in at least half the cases.

Typhoid (*Salmonella Typhi*), paratyphoid (*Salmonella Paratyphi*), salmonellosis (*Salmonella enterica*), and others

Similar to cholera, salmonella, probably the best-known disease-causing pathogen, is transmitted through unclean drinking water and contaminated food. There is a whole range of diseases caused by closely related organisms from the salmonella group. The ones named here—typhoid fever, paratyphoid fever, and salmonellosis—are all serious diseases, with typhoid and paratyphoid fever being transmitted faster. With a long incubation period of one to three weeks, however, they usually remain undetected for a fairly long time.

Compared to salmonellosis (salmonella-related food poisoning, contracted, for example, after eating insufficiently refrigerated potato salad at a summer barbecue), typhoid and paratyphoid fever only require one thousandth of the bacterial concentration for successful transmission. While classic salmonellosis caused by *S. enterica* is constrained to the gut and usually resolves itself without treatment, *S. Typhi* and *S. Paratyphi* infect other organs, too. The consequences are a high fever, organ failure, and clouded awareness, as well as severe diarrhea, intestinal bleeding, and perforation.

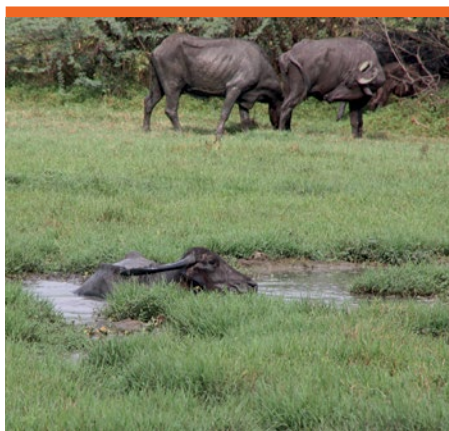
Typhoid and paratyphoid fever may be rare in urban areas in developed regions, but they are not at all uncommon in countries with ailing or inadequate water treatment facilities. As with cholera, the only source of transmission of typhoid and paratyphoid fever is other humans.

The direct comparison between salmonellosis and typhoid and paratyphoid fever is interesting, as the risk from a dead animal in a river (potential source of salmonellosis) is much lower than the risk from a small amount of human feces in the same river.

***E. coli* (EHEC, ETEC, and similar bacteria)**

As mentioned above, *E. coli* is a normal and, in low concentrations, rather harmless gut bacterium. From a microbiological point of view, that is more than simplifying things. Just as with mammals, there are innumerable variations among bacteria,

too. The bacterium *E. coli* is effectively subdivided into several strains, some of which have a pathogenic effect.



Consuming water from animal drinking places and wallows without adequate treatment carries the risk of contracting serious illnesses.

Enterohemorrhagic *E. coli*, or EHEC—thanks to various recent epidemics, probably one of the best-known strains—is so virulent that fewer than a hundred individual bacteria (a number that is virtually unverifiable before they start multiplying) are enough to cause hemorrhagic diarrhea. The germs are spread by virtually all mammals but especially by ruminants, a fact that earned the disease the label “hamburger disease.”

E. coli is also spread through water contaminated with animal dung. Unlike “normal” *E. coli*, the dangerous strains of the bacteria produce substances that optimize colonization in the gut or powerful toxins that are released in the intestine—as EHEC and enterotoxigenic *E. coli*, or ETEC, do. A long-established gut-dweller, the bacterium—regardless of its toxicity—multiplies just as fast as “normal” fecal bacteria: Their number doubles roughly every twenty minutes, leading to an incubation period of just a few days. Just as with other waterborne diseases, pathogenic *E. coli* entails severe (sometimes bloody) diarrhea, internal “poisoning” through the toxins, and reduced organ function.

As with all infection-related diarrheal diseases, the use of antidiarrheal drugs is not advised because they prevent the toxins from being flushed out of the body.

There are innumerable other similar bacterial infections—leptospirosis, for example, which is spread by rodent urine. Harmful bacteria and poisoning through bacterial toxins are particularly dangerous because they are transmitted via drinking water and cause massive diarrhea, facilitating—just as with viral diseases—the contamination of the environment and hence proliferation. The affected individual’s enormous demand for water is (too) often met with insufficiently purified water, often leading to a secondary illness in their already weakened body.

Note: Water from sources potentially contaminated with human or animal excretions must be purified using reliable methods.

Single-celled organisms and parasites

Humans play an important role in the survival of many parasites—just as parasitic diseases have been a major health hazard since time immemorial.

Most parasites harmful to humans* specifically target humans—hundreds of thousands of years of coexistence have adapted them perfectly to our bodies. This is of advantage to us, but it also carries a particular risk: They “know” the human or mammalian organism well and know how to “hide” from our immune system. This means that it usually only takes a small number of eggs or the relevant transmissive stages to cause an infection.

Now, I don’t want to scare you with horror stories of meter-long worms under the skin or in the gut. Such parasitic infestations tend to be harmless for a healthy individual and are easily treated with modern medicines. Most parasites depend on a living host—the host’s death would be their own demise. Usually they merely weaken the host body enough to stop it from attacking the parasite, but not enough to kill the host body (that being the advantage mentioned above).

A much bigger problem are tiny single-celled parasites. They are of particular concern where the drinking water supply has collapsed or is nonexistent, as they are transmitted through contaminated water and often lead to severe cases of diarrhea.

Let’s have a look at a few examples of typical parasites that can be transmitted to humans when drawing or drinking water.

Cryptosporidia (*Cryptosporidium parvum* and others)

The single-celled pathogens of cryptosporidiosis are found around the world and can be transmitted through contaminated water and food. After being excreted, the transmissive stages (thick-walled oocysts) remain active for months. Ingesting a very small amount (one to ten cells are enough) usually leads to rapid proliferation in the gut of the host, with a common symptom being severe fluid loss through diarrhea.

** With regard to drinking water I only talk about endoparasites—i.e., parasites that live inside the human body.*

The mostly mild illness resolves by itself—provided the infected individual has a healthy immune system. In emergency situations, however, the immune system is at a particular risk from lack of water, food, or vitamins. In severe cases of a reduced immune response, cryptosporidia can attack other organs, too. With a normal infection, the organisms—which resemble the parasites responsible for malaria—lodge themselves in the mucosal cells of the intestines, where they multiply and cause infections.

The oocysts enter the water with the excretions of various animals (especially sheep and cattle); often, the source of the contamination is human feces.

Although cryptosporidiosis usually resolves itself after a few weeks (and in most cases even without medical treatment), it is important to be aware of it, as the thick-walled oocysts of this fecal-orally transmitted disease can survive the usual doses of chlorine or ozone applied when disinfecting water.

Giardia (*Giardia duodenalis*)

A disease similar to cryptosporidiosis (and commonly leading to traveler's diarrhea around the world) is giardiasis, also known as lamblia. Its transmission and infection are similar to that of cryptosporidiosis, and they are largely indistinguishable in the wild. Yet it is worth presenting giardia separately, as there are repeated reports that the illness was transmitted via beavers and other rodents, for example as "beaver fever" in Canada.

Giardia are classified into different genotypes (similar to strains with bacteria), two of which are currently considered human pathogenic. These two can also infect other animals, making them in turn liable to release oocysts into the water. According to recent findings, the increase in giardiasis cases in areas with beaver populations does not arise from beavers as the natural reservoir, but rather beavers have in the past caught giardia from human sewage and have been spreading it further only since then. In regions where it can be determined that sewage has not been regularly released into the environment, it is unlikely that beavers were responsible for the origins

of the disease. The main cause of waterborne diseases generally is and has been human sewage or animal husbandry.

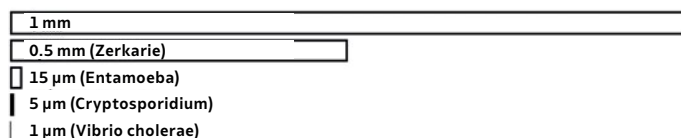
Other, more problematic bacterial pathogens than giardia in the immediate vicinity of “natural” beaver dams (or generally with large rodent populations) are tularemia (*Francisella tularensis*), leptospirosis (*Leptospira* spp.), or viral diseases such as hantaviruses.

Note: Usually, tiny amounts such as one to ten oocysts are enough to cause an infection with cryptosporidia or giardia. In that case, the infection often passes subclinically—i.e., without any symptoms. As a result of the infection, the “slightly” ill individual may develop a resistance against a certain number of the pathogens.

Amoebas (*Entamoeba histolytica/dispar*)

Amoebas are single-celled organisms that are able to move in a targeted, “crawling” manner. They have a jellylike appearance and, like cryptosporidia, are able to survive for a long time as stable cysts in water. Amoebic dysentery is transmitted through water contaminated with human sewage and is a dreaded yet common consequence of collapsed or unreliable water supplies in natural disasters and emergencies.

Once ingested, the active stages pass safely through the stomach acid and quickly multiply inside the gut. The acute illness is caused by the dissolution of intestinal cells through the blood vessels. The parasites migrate, causing infections and ulcers in the intestinal wall, eventually attacking the lungs, liver, and brain.



Relative sizes of various pathogens: Hundreds of times smaller than *Vibrio cholerae*, many viruses are too small to be represented here and are impossible to filter out.

Amoebic dysentery doesn't always erupt immediately but can remain "silent" for years before suddenly attacking several organs. One consequence of the acute phase is severe mucoid diarrhea (resulting in extreme fluid loss), fever, abdominal pain as well as ulceration of the colon, irreversible organ damage, and liver abscesses. Even after their symptoms have resolved, affected individuals often remain chronic carriers for the rest of their lives.

Note: With many parasites, it is worth noting that their dormant structures are resistant to the usual disinfecting concentrations and times. In high-risk areas (especially in subtropical and tropical disaster regions), the additional application of mechanical and/or physical disinfecting techniques is imperative.

Multicellular parasite larvae (e.g., *Schistosoma haematobium*, *Trichobilharzia ocellata*)

Apart from the eggs of various tape- and roundworms, which in theory can also be transmitted through contaminated drinking water, the larvae and active stages of trematodes are another important health hazard in surface waters around the world. Many larval stages of trematodes are able to perforate the healthy skin of an individual bathing or drawing raw water. Once inside the human body, they migrate through the bloodstream to the inner organs where they develop and multiply.

Blood flukes (the genus *Schistosoma*), for example, are parasites found in tropical regions that cause diseases such as schistosomiasis (also known as snail fever or bilharzia) in humans.

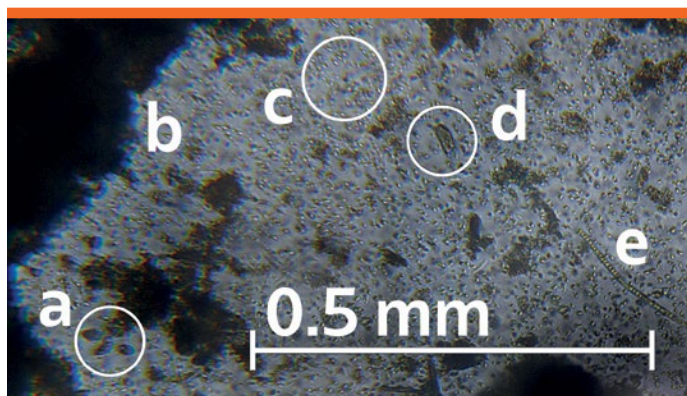
Schistosome larvae can be found in practically all tropical waters with freshwater snail populations (schistosomiasis germs depend on water snails as intermediate hosts). Once they have entered a body through the skin—which can happen by simply wading through fresh water—the different pathogens cause severe symptoms that require medical treatment.



The presence of certain water snails (pictured here: a ram's horn snail, transmitter of schistosomes *mansoni*) in a tropical body of water is a definite warning not to enter the water under any circumstances due to the risk of schistosomiasis.

A similar parasite, *Trichobilharzia ocellata*, is found in the warm waters of central Europe. Ordinarily affecting water fowl, its larvae nonetheless enter the human tissue, causing allergic reactions and extremely itchy welts on the skin. The symptoms of cercarial dermatitis, also known as “swimmer’s itch,” may be harmless but can be extremely painful.

Since the transmission of trematodes always depends on an intermediate host, a species-specific snail, all tropical waters containing water snails and liable to be contaminated in any way with human feces (via sewage inlet, fertilization, fouling by individual residents) must be considered as potentially infectious. The limiting factor for the dangerous disease schistosomiasis is the prevalence of the ram’s horn snail in a body of water. As it prefers slow and wide rivers or standing waters, the risk is comparatively low in fast-flowing jungle rivers.



Microscopic examination of detritus from the wastewater of a water purification plant: oocyst-forming single-celled organisms (a), remainder of organic particles (b), large amounts of bacteria and single-celled algae (c), amoeba (d), and filamentous algae (e).

In contrast to the infectious stages of single-celled parasites, blood flukes and their larvae are relatively large and susceptible to disinfecting agents. They can be safely removed by filtration (germ count reduction) or chlorination.

Blue-green algae

The term algae is very vague; it encapsulates different organisms that are often green in color and live in water. Of extraordinary importance for us, however, are blue-green algae that have nothing to do with what's in your fish tank. Instead, they are primeval bacteria that are among the oldest organisms on the planet. The term cyanobacteria is therefore more appropriate. They are of relatively simple structure and irrelevant as pathogens. What makes cyanobacteria so dangerous is the fact that in the right environment they can multiply extremely fast through cell division and often produce highly toxic substances. Many species, for example, can produce microcystins, which even in small numbers can cause severe nerve and liver damage, and even death. The toxin microcystin-LR produced by cyanobacteria is considered fatal to humans from as little as fifty micrograms per kilogram of body weight. Some of these toxins are also believed to be carcinogenic.

Besides blue-green algae, there are highly toxic single-celled dinoflagellates, which also produce highly potent toxins that accumulate in various organisms such as fish, mussels, and clams. While most dinoflagellate poisonings occur in tropical seas (i.e., in brackish or sea water) or by eating contaminated fish and seafood, mass occurrences of blue-green algae in fresh water are also common in temperate climates.

Large concentrations of nutrients and high water temperatures in the summer are often the cause of these algal blooms. The very large number of organisms in the water causes the water to become *extremely cloudy*. A concentration exceeding *moderately cloudy* levels is deemed to be critical.

The following applies if the turbidity (not discoloration!) of the water is moderately or very greenish, reddish, or bluish:

- With water that is no more than moderately cloudy, it suffices to filter the cellular particles out of the water to reduce the risk. The toxins are mainly contained in the integral cells.
- When using a backpacking filter, the raw water should be prefiltered thoroughly to prevent the filter from clogging up.
- When treating water with improvised methods, the water must be heated but not boiled! Boiling destroys the cells and releases the toxins. Once cooled, the majority of the dead cells sink to the bottom or float up to just beneath the surface. The water can be decanted and, if necessary, treated further.

With distinct algal bloom—i.e., very cloudy water:

- Dead fish, snails, and other small animals can often be found lying along the banks.
- Due to overcrowding, some of the cyanobacteria die and sink to the bottom where they decay, releasing their toxins into the water. The decomposition of the cells consumes a lot of oxygen; as a result, the water “dies,” and the area becomes a “dead zone.”
- If this is your only source, the water must be prefiltered until it is only slightly cloudy. Subsequently it must be treated several times using a carbon filter.

Note: With bacterial toxins, boiling is not a safe method to use, as many such toxins withstand high temperatures.

Chemical components of raw water

Ever since humans have come to depend on industrialized and automated production methods in order to meet the basic needs and indulgences of a rapidly growing world population, they have changed, polluted, and contaminated the

environment. It is rarely the so-called “developed” countries that are hardest hit by industrial pollution (which always goes hand-in-hand with water pollution); rather it is the regions mining the raw materials, producing the chemicals as cheaply as possible, and reclaiming and “recycling” our plastic and electronic waste that suffer the most. In addition to a lack of adequate sanitation and wastewater treatment facilities, improper management of highly toxic substances is in many developing countries one of the main reasons why the majority of the poor population does not have access to clean drinking water. While water with a certain degree of fecal contamination can be safe to drink after treatment with reliable methods, many chemical components remain in the ground for a long time where they can trickle into the groundwater. The assimilative capacity of surface water can neutralize this kind of pollution only very slowly (for example by storing it in plants, which will, however, enter the food cycle), if at all. As a result, the environmental damage caused by the technical (or natural) extraction of metals from the ground, by leaking oil pipelines, or by the release of wastewater from major industrial chemical plants is reversed only very, very slowly.

Note: Practically any substance is water-soluble. The level of dangerous concentrations depends on many factors: Temperature, pH, solute salts, and bioavailability all determine whether a substance is harmful or not.

While US law imposes relatively strict safety limits, some other countries have rather liberal regulations governing the disposal of hazardous waste. The pollution is particularly bad in developing countries with strong economic growth. Here (just as, unfortunately, in more developed economies), commercial goals are placed above the well-being of the population and the environment.

Of course, even natural springs can contain chemical substances in harmful or toxic concentrations—think of healing water springs containing sulfur, or simply seawater.

When traveling solo or in remote areas, you will sometimes find yourself in situations where you need to evaluate if and what kind of chemical pollutants might be present in a certain body of water. Here, we will consider the most important chemical substances most commonly found in raw water and how to assess the danger they represent.

Essentially, any substance (for example: minerals, metals, sugar, or salt) is water-soluble, but their solubility varies. While table salt, for example, is very soluble (around 350 grams per liter [3.5 ounces per 10 fluid ounces]), lead is unlikely to occur in water in compact form, especially not in an oxidized form. Although lead is poisonous, there is little risk of harmful levels of lead oxide occurring in water—otherwise all the lead pipes in old buildings would have to be replaced immediately; lead is practically insoluble in ordinary tap water.

Yet there are circumstances where this heavy metal becomes soluble in water. “Sugar of lead” (highly poisonous lead acetate, historically used as a sugar substitute), for example, is more soluble in water than salt: roughly 450 grams per liter (4.5 ounces per 10 fluid ounces). While the body can pass excess salt relatively quickly with urine, getting rid of lead takes a very long time, which is why *prolonged ingestion* even of very small amounts can lead to chronic lead poisoning.

Furthermore, some water-soluble substances are harmless until they have been transformed, for example by bacteria, into a harmful form.

Whether or not certain substances are present at dangerous concentrations depends not only on their own solubility, their actual toxicity, and bioavailability, but also on the properties of the water: its temperature, pH value, oxygen content, and the concentration of other solutes.

Often, only *very high concentrations* of solutes are indicated by discoloration, odor, or the lack of living organisms in the water. In order to evaluate the risk, it is important to take into account the surrounding area of a body of water as well as its source.

It would not be helpful to attempt to outline in this book every potentially harmful substance that could possibly be

present in water, because you would not be able to identify them in an emergency situation or crisis in the wild anyway. Moreover, as the substances occur in solute form (the homogeneous solution contains no particles), it is very difficult to separate them from the solvent.

Low levels of certain metals and organic substances such as tannin can be separated with carbon filters. High levels of solute salts, however, can only be removed from water with **demineralization** methods such as reverse osmosis, passive osmosis, and distillation.

Sodium chloride (table salt)

Many liquids have a certain **osmolarity**, the concentration of osmotically active particles in a solution. An increase in osmolarity affects other parameters, such as freezing point, electric conductivity, and density. And although different substances—such as water-soluble proteins or sugar, for example—can influence the osmolarity of water, our chief concern when looking for water is the amount of salt contained in the water (i.e., its salinity) indicated as a percentage by volume, in grams per liter.

What matters to us is salinity in relation to the osmotic value of the blood. The body's fluid balance is largely unaffected by ingested liquids with an osmolarity *below* that of the blood or the intracellular fluid (about 300 milliosmols per liter). This is equivalent to a sodium chloride solution of 0.9 percent—i.e., nine grams of table salt per liter of water. Blood actually contains a lot less sodium chloride, but it also contains a whole series of other osmotically active particles: plasma proteins

as well as potassium, calcium, and magnesium salts.



The human body contains about 100 to 150 grams (3 to 5 ounces) of salt—the same amount as is contained in just four liters (one gallon) of seawater.

For now, let us remember the maximum limit of 0.9 percent and turn to the question of whether it is at all possible to determine intolerable salt water.

Today, we know that drinking seawater with a high salt content has a negative effect on the body's fluid balance. Yet for a long time, the question whether and how much seawater was safe to drink could not be answered satisfactorily. It may be a known fact that human civilizations developed exclusively in locations with access to sufficient fresh water, and that humans, like all other land animals, instinctively prefer to drink fresh water from a spring than seawater, but certain conflicting opinions prevailed for a long time. Reports circulated, especially in the time before and during the two world wars, that told of shipwrecked people drifting at sea for weeks and ostensibly surviving on nothing but seawater.

Had the unfortunate individuals in their delirium really been able to persist for so long purely on salt water, or did other liquids, such as fluids obtained from squeezing fish, a little collected rainwater, and the morning dew play a vital role as well?

After decades of arguing, the French physician and biologist Alain Bombard sought to put an end to the scientific debate and set off on a spectacular self-experiment. In 1952, he sailed, alone and apparently without any supplies or drinking water, from the Canary Islands off the west coast of Africa across the Atlantic in order to prove his hypothesis that humans could drink almost a liter of seawater a day if topped up with liquid squeezed from fish. In fact, Bombard reached the Caribbean island of Barbados sixty days later—alive.

When the German physician and folding-boat pioneer Hannes Lindemann set off to replicate Bombard's results (setting off with a Klepper folding boat in 1956 to travel roughly the same route), he became a fierce opponent of Bombard's theories. As predicted by the medical literature at the time, after a few days of saltwater consumption, Lindemann began to experience severe edema and was only able to survive by collecting rainwater.

In fact, Bombard had not—as was reported later—survived purely on salt water and “fish juice” but had taken with him around a hundred liters (twenty-five gallons) of fresh water and obtained food and additional water from several steamships en route.

Today, we know that the consumption of exclusively hyperosmolar seawater (water with a salinity above the blood’s isotonic value of nine grams per liter) produces a negative fluid balance, thus causing the body to lose fluid over time. On the other hand, it is also true that the body is equipped with certain water stores (in cells, and bound in carbohydrates and fat), so it is able to buffer the osmolarity of the blood.

According to current scientific knowledge, we can therefore assert the following with a fair degree of certainty:

- With a perfect fluid balance, the daily ingestion of very small amounts of salt water (corresponding to a shot glass–full) may well be able to delay death by thirst for a few days.

Even if salt water has a negative impact on fluid balance, it also helps to flush certain waste products out of the body and maintain the “flowability” of the blood. However, the ingestion of salt water must be discontinued as soon as the first signs of severe dehydration appear. The issue is that salt causes severe afterburn, which must not be quenched with even more salt water under any circumstances. Therefore it is possible to live a little longer than without any water, but only if you start drinking tiny amounts of salt water on day one, which inevitably leads to immediate and relentless thirst, and edema. Losing one’s self-control in this phase and gulping large amounts of salt water would lead to instant death.

- If one’s fluid balance is already off-kilter, drinking even small amounts of seawater can bring about death. This is the more common scenario, since humans tend to avoid drinking seawater until they can no longer bear the thirst, and then try to quench their craving with seawater.

In that situation, the body quickly loses large amounts of fluid through the osmotic potential of salt in the gut. As a consequence, the body can no longer absorb water in the

gut, which leads to diarrhea (as described by Bombard, too), *a virtual death sentence in the advanced stages of dehydration*. Furthermore, the salt content of the blood increases to the extent that the kidneys become incapable of producing urine. The body retains increasing amounts of fluid (hence the edema) until the kidneys stop functioning and the body starts losing large volumes of water through osmotic diuresis—leading to certain death.

Purely from a fluid-balance point of view, humans can survive on isotonic drinks (those with the same osmotic pressure) for quite a long time. Solutions with a salinity of 0.9 percent are no longer deemed to be palatable drinking water (see below), but a healthy individual can tolerate this concentration with reduced activity levels well, even long-term.

As already described, the decisive factor is not only the minerals-to-water ratio but also whether the body is able to produce urine or not. Let's assume that we have ingested a liquid containing a little more salt than we need. As an osmoregulator, the body recognizes the imbalance and responds correspondingly: It sends a signal to the kidneys to up the urine concentration (up to 1,200 milliosmols per liter when dehydrated, equivalent to four times the blood level), as a result producing less but more **concentrated urine**. The fluid balance is eventually reestablished as the kidneys are "desalinating" the blood in this way.

Thus, even in a weakened or dehydrated body, slightly salty water up to isotonic levels can reestablish fluid balance. So say, for example, you have been shipwrecked and you have some freshwater reserves, or you have collected rainwater; this drinking water can then be stretched with seawater without having an immediate ill effect.

Note: Demineralized (distilled) water or available fresh water (collected rainwater) can be stretched with a small amount of seawater. As a rule of thumb, in salty oceans, use no more than one part salt water per three to four parts fresh water. This makes the liquid saltier than fresh water but still palatable.

Salinity levels of the seas

The salt content of the various large bodies of water around the world vary greatly. Think of the two extremes: the Dead Sea in Israel and the Baltic Sea in Eastern Europe. While the literally lifeless—apart from microorganisms—Dead Sea with its salt content of three hundred grams per liter (30 percent) is wholly unsuitable for drinking, a few liters of water from the Baltic Sea (average salinity ten to twenty grams of salt per liter, or 1 to 2 percent) are perfectly harmless for an individual with a healthy fluid balance.

Water from certain seas is safe to drink because their salinity in relation to human blood is hypotonic. Often, however, we have to assess the salt content of water from estuaries and other river sections close to the sea. In the tidal sections of large rivers, fresh water and seawater mix to form brackish water. In large rivers or those with a large tidal range, the delta of brackish water can be over a hundred miles long.

Salinity levels of different bodies of water

Source	Sodium chloride content (salinity level)	Assessment
Isotonic value	0.9%; 9 g/L	Potable
Drinking water, or fresh water	0.1%; 1 g/L	Potable
Pacific, Atlantic, Indian oceans	3.5%; 35 g/L	Demineralize
Baltic Sea	ca. 1 to 2%; 10 to 20 g/L	Potentially potable
North Sea	3.5%; 35 g/L	Demineralize
Mediterranean Sea	3.8%; 38 g/L	Demineralize
Dead Sea	30%; 300 g/L	Demineralize
circumpolar surface water	0.5 to 3%; 5 to 30 g/L	Potentially potable
(Mediterranean) coastal areas with submarine springs	0.3 to 3.8%; 3 to 38 g/L	Potable near the springs

The table above merely indicates whether water from the relevant oceans must be demineralized or if it is drinkable because of its low salt content—it says nothing about the potential presence of any pollution through local industry or sewage inlets.

Determining salinity

It would of course be useful for us to determine the salinity of water from sources with an unknown salt content.

The problem with a taste test is that the presence of other minerals in the water can strongly influence our perception. I experienced this myself a few years ago when I was backpacking around the Mediterranean, and I ran out of drinking water in a remote area. I was able to quickly identify a place near the sea where fresh water was surfacing from a submarine source. I pushed a hose into the crack between the rocks and bent down to suck up the water and spit it into a bottle. But at my first attempt at taking in a large mouthful I was retching. Containing a large amount of magnesium, the water—though actually only slightly brackish—tasted extremely bitter, so much so that I was unable to safely establish by taste how salty the water really was. Since then I have encountered the same taste in a number of freshwater lenses.

Even with pure seawater or tidal river water, a taste test is not easy. You can try this at home: Mix up different salt solutions with 0.5 grams per 100 milliliters of water (hypotonic level), 1 gram per 100 milliliters (about equivalent to isotonic level, maximum salt content for “wholesome” drinking water), and 4 grams per 100 milliliters (about equivalent to ocean salinity, unfit for consumption).

When tasting these solutions, you will quickly realize that the difference in taste between 1 and 4 percent salt content is not very noticeable: Both stronger concentrations taste unpleasantly salty. To use a known solution as a benchmark, take the taste of tears: It is roughly isotonic—i.e., the maximum salt content we can tolerate.

Virtually the only way of determining the exact mineral content is to vaporize a certain amount of water and weigh the residues. As this is difficult to do in the wild, we need to stick by the benchmark of the comparative taste of tears if necessary. Carefully rub your eyes until they start watering and taste a tear immediately before tasting a drop of salt water. This direct comparison is the most likely method of determining if the water is hypotonic (less saline than our blood) or hypertonic (more saline).

Other minerals and heavy metals

While naturally occurring levels of certain minerals—for example, magnesium—in the water have little effect on human health (although it can taste awful and sometimes lead to mild diarrhea), the situation is quite different for other solute minerals, such as toxic metalloids and heavy metals. High concentrations of arsenic, cadmium, and lead compounds, for example, as well as uranium and copper can be found in water from natural springs. In some places, such unpalatable water is bottled and marketed at a premium as “mineral water” with sometimes proven but often unsubstantiated healing powers. Yet these popular “bitter mineral waters” are in fact contaminated with uranium. In many spa towns, you can see senior citizens “taking the waters” with ceramic feeding cups, traveling from spring to spring to drink waters heavily contaminated with sulfur, manganese, uranium, cesium, and so on.

Generally, this has no immediate ill effects on a person's health, although the levels usually lie significantly above the permitted limits for drinking water. In actual fact, the danger from naturally occurring minerals or heavy metals is relatively low—as long as the consumption is not prolonged over months or years.

Note: Generally speaking, all metals with a specific weight of five grams per cubic centimeter or more are classified as heavy metals. This includes iron, even though it is absolutely essential for human and animal organisms. Not all heavy metals are of equal toxicity.

Larger quantities of heavy metals enter the water cycle through the acidification of leachate (liquid that has percolated through soil) as well as through industry and agriculture. Water escaping from abandoned mines or caves also contains dissolved minerals in high concentrations.

But how can we recognize this pollution, and what risks does it pose?

Even in small measures, many dissolved mineral and heavy-metal ions produce a distinct metallic or bitter taste. Without laboratory inspection, however, it is very difficult to tell if the taste stems from a harmless substance such as magnesium or calcium, or if harmful substances are the cause. The discoloration of the water can give us a clue.

There is, however, a relatively simple method for determining the level of contamination in a clear solution—and to reduce it without too much effort. It is based on the fact that many metals dissolve in slightly acidic water, and by increasing the pH value (i.e., reducing the acidity) of the flocculate, or precipitate, in the water. In most cases, water contains a certain amount of dissolved carbon dioxide (the carbonic acid responsible for the fizz in carbonated water), which makes the water slightly acidic, allowing it to hold mineral ions, especially calcium and magnesium, in solution. Just as warm beer goes flat by giving off its carbon dioxide, the same thing happens with ordinary water. When heated, the amount of carbon dioxide water can hold decreases, and the previously dissolved minerals precipitate as limescale (see also “Distillation,” page 180), usually white or slightly grayish in color. When other dissolved minerals in addition to calcium or magnesium are present in the water, they usually precipitate in the same manner or are literally “trapped” by the limescale particles and can be identified by their color (for example, reddish or yellowish) and partly removed by decanting (see also “Heat precipitation,” page 136).

But before you start worrying that every river might be contaminated with harmful levels of heavy metals, let’s find out how dangerous these actually are (given that in fact all types of drinking water contain low levels of heavy metals).

The problem with these substances is that in heavily con-

taminated areas, residents ingest them every day with their drinking water along with those stored



The chalky residue generated by applying heat may contain dissolved substances, which can be identified by their color.

in their food. Apart from their acute toxicity, heavy metals tend to accumulate in the human body. In some areas, whole populations suffer from chronic lead or cadmium poisoning caused by naturally contaminated water from deep wells. Adults can usually tolerate these without ill effect for longer, but infants and children often show symptoms considerably faster.

The human body is equipped with several mechanisms for tolerating many poisonous metalloids and heavy metals in food or drinking water—even if the recommended limits are exceeded significantly in the body. Arsenic, for example, though highly poisonous, was historically consumed as a drug—the so-called arsenic eaters were eventually able to tolerate multiple ordinarily fatal doses without being poisoned.

Note: In addition to natural leaching from layers of rock, mineral fertilizers are the main cause of groundwater pollution and contamination with heavy metals such as cadmium, lead, and uranium: Several tons of potentially harmful heavy metals are spread on arable land every year.

Yet the dangers posed by heavy metals are actually rather low—provided raw water is not drawn from the wastewater outlet of a chemical factory.

When taste-testing water indicates that it may be chemically polluted, the concentration can be reduced with heat precipitation prior to consumption. If your only source of drinking water for a prolonged period of time is likely to be slightly contaminated, the concentration can potentially be further reduced by **ion exchange**.

For water that is heavily contaminated with minerals and heavy metals, the only reliable methods for making water palatable are distillation and reverse osmosis.

Radioactivity

A question I'm asked repeatedly at seminars and talks is a question that I can never answer conclusively or to the questioner's satisfaction: How to assess the risk of radionuclides.

In fact, natural spring water contains traces of uranium, for example, but they generally fall below the strict legal limits for the preparation of baby food. A bigger problem is the radiation released into the environment by humans—for example, in Central Europe after the nuclear accident in Chernobyl, in parts of Japan after Fukushima, and in fields around the world in the form of phosphates in fertilizer for decades. In addition, residual radioactivity from nuclear-weapon tests in the last century will be evident for a long time to come and can lead to unintended contact with sources of radiation for the unsuspecting long-distance traveler.

Exploring the consequences of any extensive and immediate radioactive contamination caused by renewed fallout due to some sort of hypothetical nuclear accident or attack would go beyond the boundaries of this book. The complexity of such an event makes it difficult to estimate the consequences, and it is also relatively improbable. Having said that, it is quite likely for radioactive dust, for example in still heavily contaminated areas of Russia, to be blown up into the air by fires and to come down with rain many miles away. The radioactive contamination of other areas, such as the Bavarian Forest in Germany, is also a well-known fact.

The question is how to assess water sources from the relevant regions, and how to treat the water accordingly.

In view of the many kinds of potential radionuclides, I will explain the problem by using the most important ones as an example. Part of the problem is that radioactive isotopes decay at different rates and have different chemical properties. Substances such as iodine-131 and cesium-137 (among others), so often dreaded in the wake of nuclear disasters, have very different rates of decay and different degrees of water solubility and bioavailability. Iodine-131, with a half-life of a few days, quickly becomes (literally) immaterial, while half the amount of cesium-137 released will still be affecting the environment thirty years later. Just like any other chemical, they are difficult to remove with improvised methods when dissolved in water.

Most people tend to associate dangerous radionuclides with accidents at nuclear power stations. In fact, forest fires, unfiltered coal-fired power plants, naturally occurring isotopes, and agriculture are equally to blame.



Only large fallout particles can be separated, whereas any actual solutes remain in the water. In theory, iodine can be separated to a certain degree with an activated carbon filter, but thanks to its short half-life it doesn't stay around for long. Besides, it only forms very weak bonds with carbon, which is why carbon filtration isn't reliable. Cesium-137, on the other hand, could be separated with chemical precipitation methods, sedimentation, or even through ion exchange with other, harmless ions. In fact, this happens quite naturally, which explains the long-term contamination of the forest floor with cesium-137. Rainwater trickling through the ground dissolves many of the substances, which are then absorbed by microorganisms and thus remain in the ground for a long time. This can be a problem for humans—for example, when gathering mushrooms in affected areas.

By implication this means that where rainwater covers a long distance when seeping into the groundwater, a large part of the radionuclides is absorbed in the soil, which is why travelers in zones with known radioactive contamination or at risk of contamination are advised to use spring water wherever possible. In the United States, the Environmental Protection Agency does regulate radionuclides in drinking water to ensure the amount does not exceed levels that would pose a risk to public health.

When remaining in one place for longer periods of time, we can recreate these natural circumstances artificially by filling stationary filters with ion-exchange resins or thick layers of a sand-clay mix (clay is relatively impermeable to groundwater and allows water to seep through extremely slowly). When working with cation-exchange beads, for example, take care that the beads are actually suitable for the purpose.

Relevant filter fillers for coffeemakers consist largely of silica gel and contain only small amounts of cation-exchange resin.

Should you actually be planning a camping trip to the Japanese east coast or a bushcraft tour of the wild woods of Pripjat in the Ukraine, avoid consuming locally grown produce and take a reverse osmosis pump or a distillation apparatus with you. Most of the harmful isotopes can be safely separated with these devices.

Nitrite, nitrate, and other nitrogen compounds

Nitrogen compounds are another kind of residual that trekkers often worry about. Public awareness is focused on groundwater contaminated with fertilizers and industrial wastewater, but in fact nitrite and nitrate are part of the natural nitrogen cycle and occur in all soils. The problem for our water supply, however, is the dumping of tons of liquid manure and other organic fertilizers on agricultural land. These compounds accumulate in the ground layers, dissolve slowly with precipitation and are decomposed by bacteria. In the process, ammonium compounds are turned into nitrite, which in turn convert to nitrate, helping plants grow—any excess seeping into the groundwater.

Note: Many substances dissolved in surface waters are separated from the water or made harmless as they pass through sediment layers.

Spring water therefore is usually the cleanest water, but then again it may contain different harmful substances dissolved from the stone.

While nitrite, the “intermediate stage” in the degradation of ammonium, is poisonous for humans, its end product, nitrate, is generally safe. Having said that, certain pathogens in the human gut can reconvert nitrate into harmful nitrite, releasing cancer-causing nitrosamines.

With acute nitrite poisonings, the individual’s age plays a particularly important part. Nitrite is able to convert the red blood pigment hemoglobin into methemoglobin, which cannot

bind oxygen, therefore leading to “internal asphyxiation” (similar to carbon-monoxide poisoning). In adults, an enzyme can convert the met-form of the blood into its active form. Infants lack this enzyme, which is why it is important that they only consume water very low in nitrate (the WHO’s guideline value for infants is 50 mg/L of nitrate and 3 mg/L of nitrite).

In addition to reverse osmosis and distillation, there is another safe method to reduce the risk from nitrate and nitrite. The absorption of nitrite in the gut is severely limited by the presence of sodium chloride, as the two “compete” for absorption (which is why curing salts used in meat preservation processes have to contain table salt). Where raw water is suspected to be heavily contaminated with agricultural pollutants, the risk of nitrite and nitrate can be reduced—as an alternative to complete demineralization—by salting the fresh water to a safe level of between 0.5 and 1 percent.

Pesticides and other organic compounds

Monocultural farming typically requires considerable amounts of pesticides. Herbicides, fungicides, and insecticides are sprayed widely to kill “weeds” and pests.

Consumers don’t want to buy lettuces crawling with bugs, littered with holes, or covered with spots. Since pests care little whether the fields they live in are conventionally or organically farmed, organic crops need to be protected, too—but usually with poisonous plant extracts such as copper or sulfur compounds instead of synthetic substances. While modern pesticides tend to decay quite quickly, in the US “older-style” pesticides, which accumulate and can cause problems, are still in use. Similarly, poorer regions of the world understandably make use of anything that kills pests in order to protect the vital harvests.

Another factor contributing to the contamination of soil layers and therefore surface and ground waters is the disposal of chemical wastewater, waste oil, barrels containing chemicals dumped by the roadside, and so on. As so often is the case, observing the environment is an important aspect of assessing water safety: Are there any chemical factories nearby? Is

there agriculture? Are there unofficial garbage dumps?

It is almost impossible, however, to estimate what kind of toxins could possibly leach into the groundwater. Most of these toxic chemicals are organic—i.e., they contain carbon. Often, they can therefore be sufficiently bound by carbon filters and sometimes even separated from the water in their entirety.

The saprobic index

Now that you have gained an overview of the most important and most common substances found in raw water, we need to turn our attention to surface water as a habitat, as this point of view will allow us to assess water quality and hence its potential contamination with the damage factors above.

Water ecologists wanting to determine the properties of a body of water without lab equipment relatively repeatably use the “saprobic index.” I will start by explaining this ecological zoning system and its basics before looking at a heavily reduced and generalized version of the same. In other words, the zoning system I introduce below is not the “real” saprobic index but a simplified solution for the nonbiologist based on the same principles.

Imagine a perfectly clear mountain stream emerging directly from a rock—cool, clear, and clean. On its way to the sea, this little brook will turn into a murky, marshy, and foul-smelling river. In between, it will pass through all kinds of intermediate stages. This is not necessarily caused by human activity but something that occurs naturally in rivers. The process starts in the spring itself with just a few bacteria and mineral solutes. You only need to walk a few steps from the source of a river to find the first larger water organisms, creating biomass from the substances dissolved in the water and sunlight.

A thin film of algae is therefore the beginning of natural “pollution,” which by the time the river flows into the sea will be substantial. These “first” organisms are called producers, or autotrophs. Using sunlight, they create complex solid mass and are eaten by snails, small crabs, and fly maggots. These



Sufficient circulation of water introduces plenty of oxygen, leading to a balance between growth and decay.

in turn fall prey to leeches, larger crabs, or fish. Anything that dies in this food chain is consumed by fungi, bacteria, or other microorganisms—the *destruents*. The organic and inorganic substances released in the process ultimately serve as nourishment for the autotrophs, and so the cycle is complete.

The further we move away from the source of a river, the more biomass is available, either freely or bound in organisms. Plant parts and small animals falling into the river or being washed in by the rain, more contaminated tributaries joining, and human effluent all add to this biomass.

The total energy turnover of and the balance of the living organisms contained in a body of water are mainly determined by its assimilative capacity, which in turn depends on the level of oxygen it contains. Slow-flowing rivers and ponds have a much lower assimilative capacity than a babbling mountain brook, which is why another factor comes into play in standing waters: Destructuents use a large part of the oxygen bound in the water when converting nutrients into energy.

Various biological factors (such as decay, algae growth, hydrogen sulfide, and mud) that are affected by the level of nutrients and oxygen in a body of water limit the habitats available for certain animals and plants. Just as some people like living in towns and cities while others prefer living in the country or in the mountains, animals also have clear preferences regarding their habitat. A species' adaptation to their relevant environment is called their "ecological niche." Some animals prefer or depend on perfectly clear and

oxygen-rich water, while others like or need the cloaca of the sewers. Based on the presence or absence of certain animals in the water, the saprobic index allows us to determine the quality of the water.

For this purpose, all the evident animals in a defined section are collected, and each species is allocated a multiplication factor. The number and multiplication factor of all the animals found is entered into a mathematical formula, the result being an index for water quality.

In flowing waters, there is a balance of nutrient production and biological degradation. The introduction of wastewater into a river increases oxygen-dependent degradation and therefore the number of bacteria and other destruent, depleting the water of oxygen and rendering the environment hostile for more sensitive organisms in that area.

Thanks to a river's assimilative capacity, however, the river will regain its balance of natural formation and degradation processes a few hundred meters downstream. The total amount of free organic substances is now slightly higher than upstream of the inlet; the amount of nutrients in the water gradually increases on its way from the source to the sea. At the same time, the level of available oxygen continues to decrease, as it is being utilized for the intensified biological degradation processes while the river is naturally getting wider and slower and its water less mixed.

This leads to a different combination of organisms in every stretch of the river. Anglers are familiar with a similar division of bodies of water into different "fish zones," where the presence of certain characteristic fish indicate the water quality (although I'm not suggesting you catch a couple of fish for testing purposes every time you collect water).

One great advantage of determining water quality with the saprobic index is that it also allows you to recognize other "invisible" pollutants such as sewage leached through the ground, an inlet below the water level, or other contaminants further upstream.

You can see this for yourself quite easily in your own local environment. In a creek or river near you, look for the inlet

of your local sewage treatment plant. This is where large amounts of solute nutrients are introduced. Walk ten or so meters upstream of the inlet, turn over a few flat stones near the riverbank, and count the leeches you can see. Do the same fifty meters or so downstream, and you are likely to be surprised. The introduction of the nutrients leads to an enormous increase in the number of leeches (and a huge reduction of all other creatures in the same place).

Now, this doesn't mean that all animals only live in a particular water quality. Rather, there are animals that are tolerant and able to adapt to any given water quality (**euryecious species**), and there are those that only survive in a particular water quality (**stenecious species**.)

Apart from the problem with euryecious species, which are difficult to ascribe to a particular water quality, the concept of the saprobic index suffers from the fact that under certain conditions, some bodies of water receive a "bad mark" even though they are actually perfectly clean. Very remote freshwater springs, slightly brackish waters, and tannin-related acidic rivers, for example, cannot be assessed conclusively via the saprobic index. Furthermore, the application of this system proves difficult with standing bodies of water such as lakes or ponds. For them, we must determine their trophic state first.

Indicator species

Since we need to assess water quality quickly and safely independent of location, we will examine some fairly stenecious animals that occur globally, are easy to identify, and are also typical for a particular water quality. While water ecologists may spend hours standing knee-deep in water with their nets, catching and identifying everything they can, we will take a more pragmatic approach.

For our purposes, *the presence of a large number of individuals from one indicator group typical for good water quality will be sufficient evidence*. If we can't find any, it may mean that the water quality is not good enough for those animals (or that you didn't look hard enough). We therefore have to lower our water quality assessment to the next level at which



Fish gathering just below the surface is an indicator for low oxygen levels and high concentration of nutrients in the water. The image also shows sewage-related bacteria.

we found a few indicator species. The presence of a species representing poor water quality, however, does not necessarily mean that the water quality is poor, as long as there are numerous animals from a species indicating better quality.

The simultaneous presence of numerous indicator animals from two very different groups (for example, water lice and caddis fly larvae) makes it safe to assume that there is a small wastewater inlet nearby, temporarily raising the nutrient content until the water quality improves further downstream thanks to the assimilative capacity of the river. In such an event, it is advisable to walk downstream a few hundred meters and test the water again, or to treat it with a reliable method.

Water quality is divided into four different classes that serve as reference points for the necessary treatment methods. While the water quality of a river reduces naturally on its way to the sea (as explained above), large numbers of organisms indicating poor water quality (especially in flowing rivers) are usually a sure sign of contamination with sewage or with industrial or agricultural waste.

Trophic state

In standing bodies of water, it is impossible to determine the water quality by indicator organisms alone, as the waters in lakes mix only very little or not at all (with the exception of the spring and fall circulation phases). In fact, the water is layered: The coldest water, at 39.2°F (4°C) is found near the bottom, warm water under the sunlit surface, and in between there is a thermocline layer, below which the temperature sinks and the density increases drastically.

Organisms that have died sink to the oxygen-deprived bottom where they slowly rot or decay anaerobically; this

removes organic substances from the water and stores them in the slimy sediment known as sapropel. Decay at the bottom has little impact on the upper water layers, as the layers are spatially separated, which is why the water quality of a lake is assessed with a “trophic state index.” In the oxygen-rich surface layers of standing water, the degree of pollution is determined by the concentration of phosphate, nitrate, and ammonium in the water and can be determined by the number of green producers (single-celled algae) present. The more polluted a lake, the richer its water is in nutrients. This is called eutrophication.

One important indicator for the trophic state of a lake is its visibility, normally measured with a contrast disc on a rope lowered into the water from a boat. The differences between the visibility levels for important trophic states being very large, a visual assessment from the banks will suffice for our purposes. Besides, mass accumulations of plants in and on the water also indicate eutrophication—i.e., an excess of nutrients.

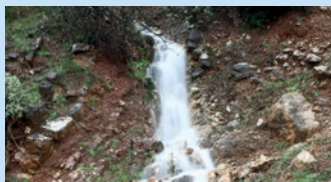
We take the following estimated visibility levels as a guide:

- more than ten meters
- one to ten meters
- less than one meter
- less than ten centimeters [four inches]

Assessing water quality

Many typical indicator organisms are easily identified. Usually the relevant animals are found under flat stones, clinging or latched onto wood and leaves. Without having to set foot into the lake, you can examine from the banks water-loving plants such as reeds and cattails as well as tree branches hanging into the water.

Note: Obviously, the search for indicator organisms must be restricted to bodies of water where there is no risk of parasites (such as schistosomes), large animals (such as crocodiles or hippopotamuses), or drowning!



Water gushing directly out of a rock is safe to drink without prior treatment anywhere in the world.

NOT POLLUTED OR SLIGHTLY POLLUTED

Water is usually safe to drink as is.

Human habitation:
can be ruled out

Visibility (standing water):
more than ten meters

Turbidity:
no visible cloudiness

Discoloration:
none

Odor / taste:
neutral

Animals:
– usually none or very few
– occasional insect larvae such as mayfly or stone fly larvae
– dark Turbellaria

Bottom features:
sandy, rocky, or gravelly; free from brownish film

**Riparian vegetation
(along the banks):**
sparse; mosses and occasional ferns



Clear, fast-flowing streams are common in the lowlands and represent a safe source of water.

MODERATELY POLLUTED

Remove any suspended solids from the water (germ count reduction) as a minimum.

Human habitation:
unlikely or little

Visibility (standing water):
one to ten meters

Turbidity:
slightly cloudy

Odor / taste:
inoffensive, slightly pond-ish

Animals:
– river limpets
– sometimes large numbers of amphipods in algae blooms
– tubes and larvae of various caddis flies
– small fish

Bottom features:
sandy, sometimes slightly muddy; lower sand layers have a brownish color

**Riparian vegetation
(along the banks):**
small shrubs, grasses, ferns, trees such as willows and pandanus



Severe pollution due to human habitation along the water.

POLLUTED

Water must be treated with reliable methods.

Human habitation:

Habitation and introduction of (untreated) fecal matter must be suspected.

Visibility (standing water):
less than one meter

Turbidity:
moderate to very cloudy

Odor / taste:
moldy to slightly foul

Animals:

- mass occurrences of single-celled organisms and small crustaceans (water fleas) and algae (see “Turbidity,” page 79)
- larger fish such as carp, whiting, or catfish; larger crustaceans such as crayfish or Chinese mitten crab
- bloodworms, sludge worms, water lice, river snails, ram’s horn snails (schistosomiasis risk in the tropics!), large number of various leeches

Surface:
duckweed; water hyacinths; very dense algae strings; slimy, stringy, or stringlike biofilm

Bottom features:
often very weedy or muddy; the lower sand layers are blackish in color; strong smell of hydrogen sulfide

Riparian vegetation (along the banks):
reeds, many overhanging trees



Clear water, but heavily polluted: Only sewage-related bacteria can survive in this water. (Photo credit: Uwe Halbach)

HEAVILY POLLUTED

Water unfit for consumption without reliable treatment methods, or, in the event of chemical contamination, without distillation or reverse osmosis

Human habitation:
undetermined

Visibility (standing water):
less than ten centimeters [four inches] (Beware: Chemically contaminated water may be completely clear!)

Turbidity:
very cloudy; chemical contamination potentially without visible cloudiness

Discoloration:
undetermined, potentially neon-colored

Odor:
strong odor of decay, sulfur, or fecal matter; potentially chemical (gasoline), pungent

Animals:
– possibly sludge worms, otherwise no living animals present
– dead insects, land animals, or fish in the water

Surface:
oily film; possibly mass occurrence of water hyacinths or duckweed; slimy, stringy, or stringlike biofilm

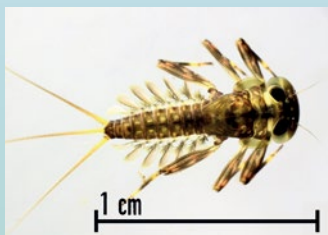
Bottom features:
sulfur and other sewage-related bacteria (sometimes appearing whitish from a distance), sometimes deep black or with a dark crust

Riparian vegetation (along the banks):
undetermined; potentially sparse or rampant

Indicator organisms



Dark turbellaria (no cross-striation): indicator for low pollution levels



Larvae of mayfly (pictured) or stone fly: indicator for low pollution levels



River limpets: indicator for low to moderate pollution levels



Amphipods: indicator for moderate pollution levels



Caddis fly larvae: indicator for moderate pollution levels



Water fleas (cladocera): indicator for high pollution levels



Freshwater snails: indicator for high pollution levels



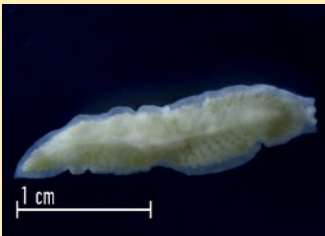
Mass occurrences of aquatic plants: indicator for high pollution levels



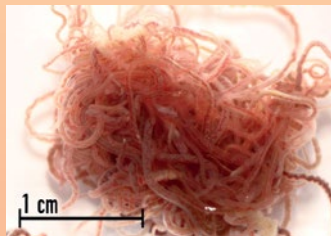
The leech (*Glossiphonia heteroclite*): indicator for high pollution levels



Water lice: indicator for high to very high pollution levels

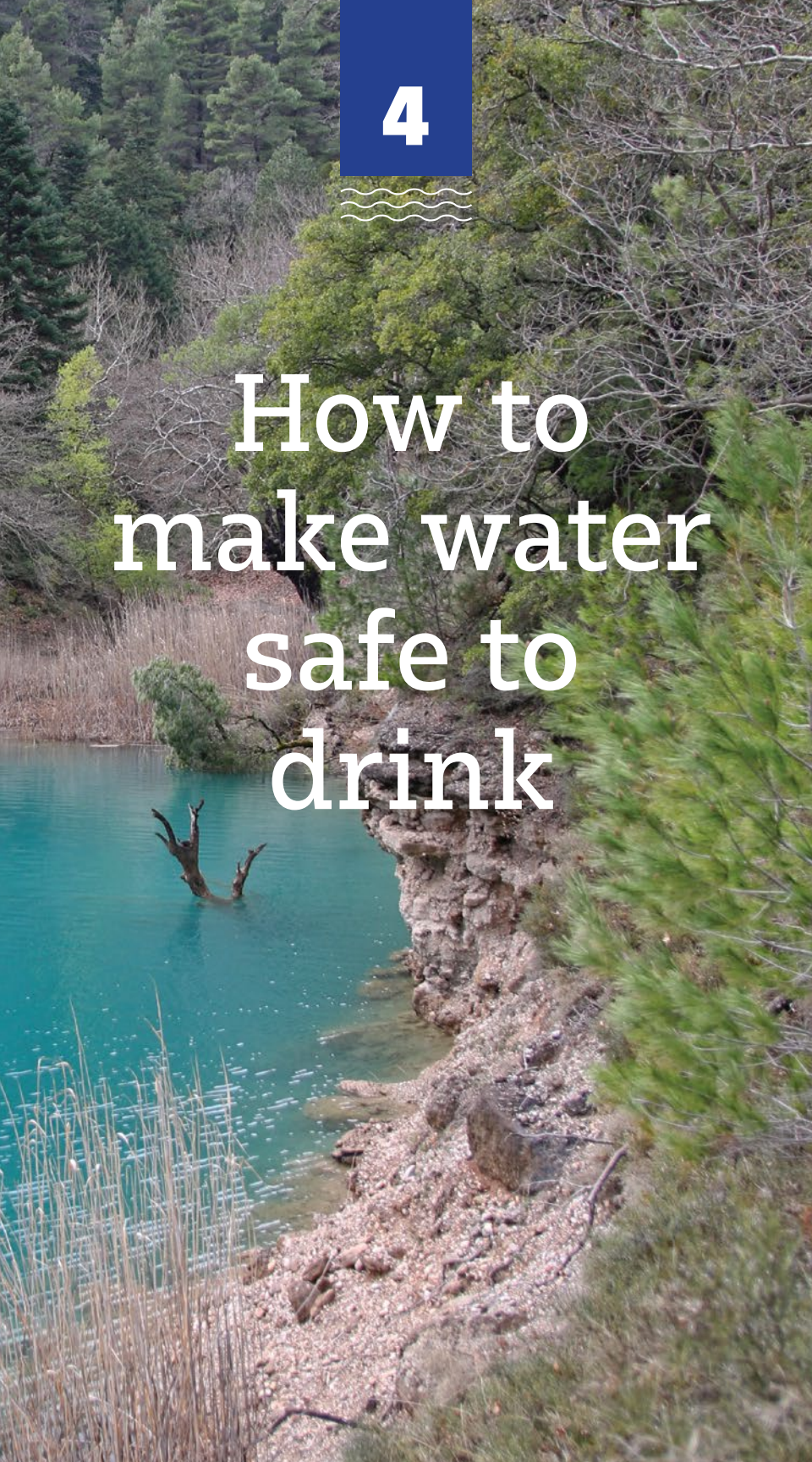


White turbellaria: indicator for high pollution levels



Sludge worms: indicator for very high pollution levels





4

How to make water safe to drink

How to make water safe to drink

Having gained an understanding of what types of pollutants can occur in raw water and how to recognize them, you can now tackle the question of how to separate pollutants from water effectively. As pollutants vary wildly in shape, size, solubility, and toxicity, as well as in their chemical and physical interactions with raw water, it isn't always possible to produce drinking water by using just a single method. Combining methods often produces the best results.

Water treatment methods fall into the following categories: *preparation*, *disinfection*, *purification*, and—to be examined in the final chapter—*preservation*.

Ideally, of course, you would collect clear raw water to begin with, but generally speaking, any solid particles must be removed from the water before removing any dissolved substances. Chemical contaminants can only be separated completely (if at all) with carbon filtration, precipitation, **adsorption**, distillation, or reverse osmosis. Particles suspended in water can impede treatment methods as well as clog the filter. It is therefore essential that the water be as clear as possible before moving on to disinfection and purification methods.

There are two types of disinfection, or sanitization, methods: reliable and unreliable. You could, of course, argue that unreliable methods should have no place in our repertoire,

but in practice that isn't always possible. In many situations with limited resources and tools, it is simply not possible to make water 100 percent safe—that is, to remove *all* disease-causing pathogens.

In the absence of water purification tablets or filters, or without the ability to make a fire, the options are already very limited. Furthermore, the period between the first need for water and making a fire (which in an emergency may well take a couple of days) or the gathering of all the required materials to purify the water can be bridged with unreliable or inefficient treatment methods.

As described in the introductory chapters, in an emergency, every drop of clean drinking water counts, literally. And since we need to drink regularly (at some point, thirst becomes unbearable and it is just a question of time until we drink contaminated water), it makes sense to be aware of unreliable—or, more correctly, germ count reduction—methods, too.

Unreliable methods reduce the number of bacteria and protozoa in the water at best to such a degree that any waterborne diseases would be experienced subclinically, or symptom-free. And some treatment methods are not capable of filtering disease-causing pathogens smaller than single-celled parasites or bacterial conglomerates.

Also, depending on the quality of the raw water, it is not always necessary to apply all of the treatment methods. Many bodies of water are sufficiently clean for their water to be consumed untreated. Here, simple germ count reduction can eliminate any potential risk. With seriously dirty water, or with water that is *known* to be contaminated with disease-causing pathogens, unreliable methods should only be used in an acute water crisis.

Reliable methods, on the other hand, can turn liquids from the filthiest cesspools into drinking water. However, the efficiency, effort, energy requirement, and yield of reliable methods can vary enormously depending on the degree of pollution. Taking preparatory steps can optimize the process of generating drinking water.

Preparation methods

Key



Yield

☾☾☾ **Small amounts**—in a water crisis, sufficient to delay dying of thirst

☾☾☾ **Medium yield**—with reduced consumption, sufficient to cover the daily need

☾☾☾ **Large yield**—at least enough to cover the daily needs of one person with normal activity

Purification Efficiency

■ **Raw water**—not a treatment technique but a preparatory activity

■ **Germ count reduction method**—this method reduces the number of germs to the order of the indicated number—e.g.,

1 = 1:10

3 = 1:1,000

2 = 1:100

4 = 1:10,000

Repeating the process and/or combining with other germ count reduction methods further increases the efficiency.

■ **Reliable method**—removes practically all harmful germs from the water.

Sedimentation

■ ☾☾☾ **1** Drawing raw water from a lake or pond disturbs and mixes the water. In flowing bodies of water, large parts of the detritus on the bottom are constantly lifted into the water by the current. Both of these effects make the water in a collection container cloudier (due to the suspended solids) than the body of water it was taken from.

Leaving the collected water to settle in the shade allows the heavier particles to sink to the bottom while the lighter ones, such as floating protozoa and algae, gather on the surface. Actively swimming organisms often collect either on the light-facing side or in the darker

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Water taken from a river must be left to settle for half an hour to allow its mixed components to separate.



areas of the vessel. Any potentially present phages are given the opportunity to reduce the number of germs and/or to limit the potency of any aggressive ones. At the end of the sedimentation process, the water must be carefully decanted.

## Heat precipitation



The solubility of gases in water behaves in the opposite way of solids. While sugar and salt dissolve more easily in warm water, the concentration of oxygen, carbon dioxide, and other gaseous substances decreases as the temperature increases. The loss of carbon dioxide (or carbonic acid, the “fizz” in carbonated beverages) makes the water slightly less acidic, further reducing the solubility of other substances in the water.

When heating “hard” water, limescale, also known as tartar, forms in the heating vessel. A carbon compound, it is found in practically all natural waters. During the crystallization process, various amounts of metals present in the water become trapped in the solids. Heat precipitation is therefore a good method to remove a certain amount of solute metals from the water while also indicating (by the color of the scale solids) any heavy contamination with chemicals.

Heat precipitation is also applied on very cloudy water with a high concentration of algae. Often the cell density is so high that they cause water filters to become clogged quite quickly, after a few liters (a gallon) or so. Heat kills any algae, bacteria, and protozoa in the water; after cooling, they sink to the bottom. With potentially hazardous levels of algae, heat precipitation is a way to separate the toxins contained in their cells. It is important to note that with high levels of algae, the water must be heated but *not boiled*, as boiling destroys the cells and discharges the contained toxins into the water. Once released into the water, they are nearly impossible to remove completely. Sometimes, a dense, solid slime film forms on the surface after heating; this can be skimmed off. The procedure can also be carried out inside a dark container in the sun, bringing it to a temperature of 140 to 180°F (60 to 80°C). At the end of the process, the clear remainder must be carefully decanted.



## Oxygen precipitation



Raw water from oxygen-deprived sources (polluted seepage springs, ditch water, etc.) can be tested with oxygen or air precipitation for the presence of any dissolved substances and heavy metals, which can then be partly removed using the same method. The result is similar to that of heat precipitation, but the procedure is simpler: Raw water is poured into a bottle, ensuring that there is enough air inside, and then shaken vigorously.

Shaking dissolves oxygen in the water, which oxidizes compounds in the water from, say, iron or manganese (as hydrogen carbonate) into solid particles (hydrated oxides). These can be sedimented and decanted. Shaking also separates some of the dissolved carbon dioxide from the water, which precipitates as limescale, as it does with heat precipitation. The amount of limescale generated, however, is much lower than with heat precipitation.

Oxygen precipitation in a bottle is not effective enough to treat heavily polluted water. Usually only a fraction of the substances present in the water is separated. It is therefore paramount that where the water remains significantly cloudy after shaking, the process is repeated until no more crystals form. Before each new burst of shaking, replace the air above the water in the bottle. This is achieved by simply decanting the water into a different container or, with flexible plastic bottles, by squeezing the sides repeatedly.

Oxygen precipitation is also suitable for testing whether any tea-like discoloration of the water is caused by iron compounds or tannins.

## Chemical precipitation



Chemical flocculants (or flocking agents, substances that cause particles in liquid to aggregate) play a much greater part in industrial water purification processes than they do in improvised drinking water treatment. The aim of chemical precipitation is to bind substances dissolved in the water together so that they form larger crystals. Amalgamating



very small suspended particles and germs results in particles heavy enough to sink.

When applied correctly, this process can remove substances in their entirety, but the solution must be formulated accurately—pH, temperature, and flocking agents must be measured exactly.

This isn't easy to achieve with a continuous-flow process, which is why substances such as EDTA, which sequesters metals, are best avoided: Any excess agents remaining in the drinking water can cause problems with the body's mineral balance.

Flocculants such as aluminum sulfate or potassium alum (the latter known to many travelers in the form of crystal deodorants or styptic pencils, which stop bleeding from small cuts or leeches) are less demanding. However, they should not be used long-term or in high doses, either, if they can't be completely separated from the water afterward.

To avoid overdosing on these chemical substances, it is advisable to titrate: In a large container, add the flocculant drop by drop into the water while stirring slowly. Cloudy, milky streaks will appear, indicating the start of crystallization. Keep adding the flocking agent until no new streaks appear. If the water is already too milky to see if there is enough substance left for the added flocculant to combine with, stop titration, let the solids settle, and decant the liquid. Add a few more drops to the clarified water. If no new streaks form, move on to disinfection methods.

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Dissolved minerals precipitate when small amounts of dissolved potassium alum are added to the water. Sedimenting or filtering the crystals removes the largest part of the alum.



## Decanting

💧💧💧 Maybe you are familiar with decanting in the context of old wine, where the word is sometimes used incorrectly to mean aerating wine. In fact, decanting is the careful tipping of a container in order to separate sedimented components (e.g., wine tartrates or, in our case, more likely detritus and sand). By holding the raw water container at a slight angle after sedimenting or precipitating, solids floating on the surface can be poured away. Once the top layer has been discarded, the clear middle layer is slowly poured into another clean container. Stop decanting when there is still a generous amount of water above the sediment at the bottom.

It is essential to hold the container at an angle the whole time. Uprighting or knocking the container causes a current that disturbs the sediment again.



Corrugated or structured PET bottles are particularly suitable for decanting, but you can use any other container (transparent, if possible) to separate the water layers.



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After sedimenting or precipitating, the lighter components float on the surface while heavy sediment and dead cells have sunk to the bottom. Careful decanting allows the clear water to be retained.

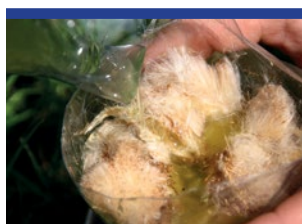
Prefiltration

💧💧💧 Generally speaking, raw water should be prefiltered before any actual treatment until any visible turbidity has disappeared and especially until all larger particles have been removed. First, the water is decanted to remove leaves, detritus, and any potential dead or immobile single-celled organisms.

If this doesn't eliminate all the small suspended particles, such as clay, follow up with an improvised prefilter using any densely woven material such as pressed gauze, tampons, kitchen sponges, pressed seed hairs from cattails, thistles, or fine hay. Where those materials are not available, fine gravel layered sufficiently thickly can be used to create a similar effect, provided it has been prewashed to separate very fine particulate that would cause cloudiness of its own. Alternatively, dry gravel can be thrown into the air repeatedly using a plate or a bowl held at an angle.

There are no limits to the imagination when it comes to constructing a prefilter. It doesn't matter whether you strain the water through a stuffed funnel made from leaves or bark or if you are using a bottleneck or other improvised container, as long as the water comes out significantly less cloudy at the other end—and, as with all filtration methods, provided there is no bypass. Backpacking filters often come with prefilter stages integrated in the suction hose in the form of sieves or small nets, but they are often too large-meshed and allow filter-clogging particles to pass through.

A simple prefilter made with plant fibers can remove a large part of the cloudy particles and larger materials.



Nonwoven fabric filters

Although removing stringy algae and larger suspended solids from raw water with paper tissues and clothing works quite well, it is far more difficult to eliminate smaller suspended substances in order to achieve, for example, a reduction in turbidity from over 200 NTU to under 50 NTU. This may be necessary when preparing eutrophic water for SODIS (solar water disinfection), when suspecting contamination with toxin-producing blue-green algae, or when clarifying raw water in the field with chemical agents or with a hollow fiber filter without the ability to construct a sand filter stage or a drip filter each time.

Fine nonwoven fabric filters come in handy especially on trekking holidays: They are lightweight and ideal for clarifying water relatively quickly. For example, there are filter bags on the market designed for prefiltering water in ultrapure water systems with a pore size of roughly five micrometers that only cost a few dollars a piece. These bags resemble tea bags but are of a considerably finer mesh. For larger volumes of water, needle felt filter bags (available with a filter strength of up to twenty-five micrometers) are more suitable.



Filters made from nonwoven fabric look like tea bags but are significantly denser. They allow for the removal of suspended particles that would impede later purification methods.



Disinfection

Drip filtration

Filtering microscopically small particles from water is a more sophisticated process than might be assumed. Bacteria, algae, and protozoa will find the smallest gaps through which to escape. Water, too, will always take the path of least resistance, which means that one small mistake in the construction of a water filter renders it useless or unreliable.

Commercial filters consist of a ceramic, plastic, or fiberglass element, baked or pressed compactly, with a porous wall with a precisely defined lattice size. Often the pores are in the area of five micrometers. These tiny holes retain all protozoa and many harmful bacteria and usually only let through the much smaller viruses, water, and the substances dissolved in it. Producing such an ultrafine mesh with natural materials is difficult but not impossible. By using improvised filter stages, a reliable treatment can certainly be achieved.

When constructing a filter, a few things need to be remembered. First and foremost, the methods listed and tested here will only work as described when built with the greatest care

A commonly recommended method that is best avoided: Filtering water through fabric leaves a bypass, allowing more water to travel around the filter than goes through it.

and using only suitable materials. Using different materials will produce different results.

The most important thing to do is to ensure that there is no bypass in the filter. In a sealed container, this means that the individual filter layers must be of sufficient thickness and carefully compressed. A single drop bypassing the filter medium can transport millions of germs into the cleaned water. For example, using suspended triangular bandages, socks, or similar items to contain the filter material allows the dirty water backing up behind the filter material to travel past the filter media straight into the collecting container. Even if it produces a few drops of clean water, they are immediately recontaminated by the majority of the raw water bypassing the filter. And yet instructions for such unsuitable filters are commonly found in various military and other survival guides. No wonder improvised water purification has a bad reputation.

Not getting ill after drinking water from a mountain stream filtered through a sock is not a sign of an expert filtering technique—mountain streams are practically drinking water. Doing the same with water obtained from the lower reaches of the Ganges or the Nile, the result is likely to be very different.

A sure sign of a well-constructed drip filter is water trickling out—without any extra pressure applied—at a rate of around one droplet every five to ten seconds. Water running freely out the other end indicates that the filtration effect is probably too low.

Filter housing

An improvised filter needs, as mentioned before, an absolutely water-tight enclosure. Suitable natural materials include pipes made from bark and sealed with resin, cane,



or bamboo, and hollowed-out pieces of wood. Bound leaves lack the necessary strength and stability, so they are only suitable for prefiltering.

In addition to natural resources, manmade materials such as water bottles, plastic bags, condoms, rescue blankets, and pieces of hose can also be used. While solid pipes with a sealed bottom can be used for layered filters, softer containers such as bags and sheets must be used with filter candles. Depending on the filter medium used, a reliable treatment can be achieved, whereas sediment filters are mainly applied to reduce the germ count because of their relatively large granulation.

Sediment filtration

   **4** Before assembling your layered or sediment filter, fit a suspension device on one side of the casing, then fill and compact the other side tightly, leaving a central hole no wider than one millimeter.

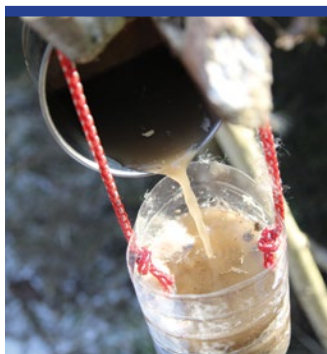
Fill the casing with various layers of clean sand or gravel. Any bacteria or germs present in the dry sand are harmless to us if ingested.

If sand and gravel must be taken from the same source as the water itself, they can be disinfected via SODIS (solar water disinfection) for filtration media beforehand.

Sediment filters are assembled bottom up, starting with the fine filtration layers at the bottom and finishing with the rougher layers at the top. Often, a charcoal stage is integrated in the filter as well. In that case,

a thick layer of coal is placed at the bottom of the housing before filling with sand and/or gravel.

Before inserting the filter material, start by arranging



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A weak suspension of mud and water condenses the sediment filter and can be used to test for any bypasses.

a layer of fibers (which generally means a dense layer covering the entire diameter of the housing, like the ones used for prefiltration), on top of which are added—if available—several centimeters of small pieces of charcoal. Place the container in an upright position, and do not shake, knock, or lay it down again. Using a rounded wooden stick, compress the coal and spread it out evenly. Add another layer of fibers and top it with filtration layers made of

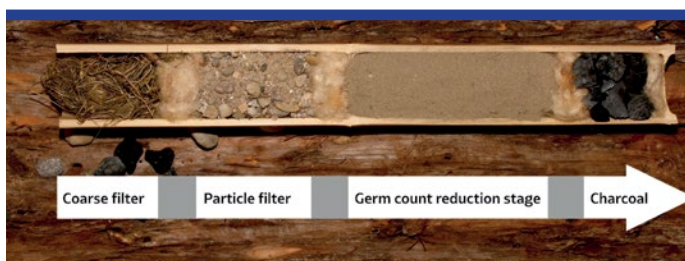
1. sand, as fine as possible
2. sand mixed with fine gravel
3. fine gravel
4. fine gravel mixed with coarse gravel.

Each section should be several centimeters thick, compacted (without shaking) and separated from the next one by a thinner layer of fibers.

Top the assembly with a bunch of coarse fibers to retain any large particles from non-prefiltered water. They also help to prevent the sediment layers from being disturbed and mixed when the raw water is poured in.

Before the actual filtration process, prime the filter by running water through that is then discarded. This removes any fine dust particles and allows the layers to settle.

Ideally this is done with water that has had a small amount of mud or clay added to it and been left to sediment. The residual particles that make the water cloudy are less than one micrometer in diameter and therefore the same size range



The individual layers of the sediment filter must be added and compacted carefully. A germ count reduction stage of fine sand is vital for the purification process; it has to be as large as possible.

as bacteria. When the cloudy water is decanted into the filter, these small particles settle into any gaps, and the filtrate acts as a functional check: If it is significantly clearer than when it was poured in, the filter is working.

During the filtration process, which can take several hours per liter, keep filling the filter to keep the pressure up. Be sure to remove the collecting vessel when filling the filter to keep any raw water spillages from recontaminating the filtered water underneath, which would require starting the process all over again.

### Clay pot filtration



If you have traveled in Egypt or Morocco, you have probably noticed water-filled clay pots hanging from trees in the shade, with a drinking cup placed underneath. These jugs are not made of ceramics fired (and sintered) at high heat, but of clay fired at relatively low temperatures. This earthenware is relatively weak and pervious to water. Water poured in can find its way out through the vessel wall in the space of a few hours, being filtered and cooled through evaporation on the way.

We make use of a similar principle when treating water. The size and shape of a clay pot filter resembles a large mug, made ideally of very fine mud or clay. With the addition of a little water, the material can be shaped and compressed into an elastic mass. This lump is then mixed with some organic material, kneaded well, and compacted further. Suitable materials include fine grass seeds, fine rotten wood, wood flour, straw, and animal manure. The mixture should contain one third organic matter and two thirds clay. The blend is then formed into a mug and left to dry in the shade for a while.

To fire the filter, light a small fire and slowly push the filter increasingly closer toward the heat, turning the mug frequently to allow any water residue to evaporate. Do not place the mug directly into the embers. Once the clay has the same light color on all sides, cover the mug with embers and keep it at that temperature for about half an hour.

The organic components burn away during the firing, creating invisible hairline cracks and pores in the vessel wall.



Without them, the rich clay may be too dense to allow the water to be forced through the walls by gravity alone. It is advisable to prepare several mugs at once, as they tend to crack during firing.



Thanks to the large filter surface and the small pore size of clay pots, water is purified quickly and reliably.

The advantage of these clay pot filters is that they can generate drinking water quickly and whenever necessary. If, for example, you don't have enough time to bring water to a boil when traveling, you can collect and treat a mouthful of water within minutes.

Another handy method is to sink several of these filter pots in the muddy banks of a body of water. The water will slowly seep into the mugs and can be suctioned off regularly. Obviously, the same filter can always only be used "in the same direction." When the filter medium becomes saturated after a time, simply polish it with some sand, which opens the pores again.

## Candle filters

Obviously, a plastic bag cannot be filled with sediment layers, so we use a different method here. The individual filter stages are applied in separate bags. The most common methods are wood and clay filters with a subsequent charcoal filter stage. Each filter can be used with multiple filter candles (of the same type), which allows the water to run in parallel and hence more efficiently. Here, too, we use a coarse filter medium first before finishing with a finer one. The raw water must be prefiltered before the first filtering stage, as the surface of improvised filter candles is pretty small and gets clogged quickly.

### Wood filter candles



Wood—or more precisely, the xylem of a plant—contains narrow vessels, or vascular bundles, with a diameter of around 5 to 10 micrometers. Part of a complex structure, interconnected with tiny pores and narrowing at the “seams,” these vessels usually make for an effective pore size of less than 5 micrometers in deciduous plants and around 0.2 micrometers in coniferous ones. These “bottlenecks” retain practically all animal cells or **single-celled pathogens** as well as many bacteria and bacterial conglomerates.

**Note:** Filters made from deciduous wood have a higher yield but don’t retain all single-celled bacteria. Using coniferous wood takes longer but removes even larger viruses. Avoid using vines or climbing plants; their vascular bundles are usually significantly larger (up to one millimeter in diameter). Make sure that the wood is nontoxic, does not have any cracks, and that the pith is undamaged.

A wood filter candle is basically a piece of wood the shape and size of a thumb. The wood is peeled and rounded off on one side, which enlarges the surface area and so prevents the filter from clogging up too quickly.

### Clay filter candles



As we have seen with clay pot filters, clay makes an efficient and dense filter medium. Clay filter candles are particularly useful when the quality of the available clay is not good enough to form mugs.

The procedure is similar to the production of clay pot filters: Add a little water



A plastic bag and a piece of string are all you need to prepare a candle filter, which—with the right choice of wood—provides surprisingly effective purification.



to clay-bearing sediment until it becomes malleable, then add some organic matter. Form a longish roll and cut it into several pieces. Dry and fire these clay candles as you would the pots (see page 145).

Once the candles have cooled down, each one must be checked for cracks (especially when the clay is crumbly). The filter candles will have an average pore diameter of less than one micrometer and are—like clay pot filters—a reliable treatment method.



After firing, clay filter candles must be checked for damage. They can easily be produced in large numbers.



Filter candles must be tightly sealed—water must not be allowed to bypass the filter and recontaminate the filtered water in the collecting container.

The big drawback of these filter candles is that despite their excellent filtration efficiency, their throughput is relatively small (one to seven hours per liter). Sealing the bag allows the pressure to build up, which accelerates the process considerably.

Where mud and clay are not available, a variety of rocks can be used instead—sandstone, for example. To test whether a stone is suitable, dab a drop of water on its surface, ideally on a side where it broke off from another part of stone. If the water is adsorbed and spreads into the surface, the stone is likely suitable. Due to the large

differences in the composition of rocks, it is not possible to make realistic assumptions regarding efficiency or pore size.

### Charcoal candle filters



After filtering through any of the filters described above, a charcoal candle filter can be used to improve the taste or to remove any organic substances.

Simply take a cylindrical piece of ember (that has cooled down and stopped smoking) from your campfire and utilize like a wood filter candle.

## Suction filters

💧💧💧4 Water treatment using a suction filter partly overlaps with water generation in a suction or infiltration well (pages 44–45). With a suction filter, the priority is not obtaining water but purifying it and reducing its germ count. Especially with suspicious bodies of water that regularly flood their banks and so contaminate their environment, a suction filter is a good option for obtaining relatively safe drinking water in the absence of fire and vessels. The basic construction of a suction filter is the same as a suction well: a pit in a wet subsoil.

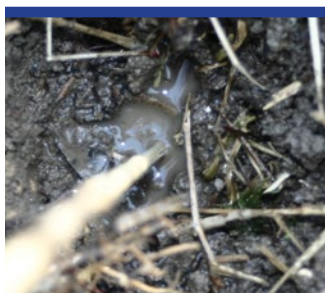
In contrast to a suction well, the bottom of a suction filter is lined with fabric or fibers, depending on availability, and then topped with fine sand, leaving a gap of around ten centimeters (four inches) at the top. Take a hose or cane and fill the bottom end with small pieces of charcoal or fibers so that you can still suck air through it. Insert the tube into the center of the pit and seal and compact the content of the pit around the tube with moist earth.

Sucking on the tube slowly pulls the water through the ground, prefiltering it through the soil layers, as in a suction/infiltration well, and further purifying it through the fine sand.

## Backpacking water filters

💧💧💧 When looking into water purification options for travelers, you cannot get around backpacking filters. Very small in size, these technical gadgets are often standard equipment for tours into backcountry. When used

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A suction filter enables you to extract water from moist sediment layers and to purify it in the process, thus combining a suction well with a filter in one.



correctly, they can make many raw water sources drinkable.

The structure of a basic backpacking water filter resembles a tire pump. Water is sucked directly from a natural source by means of a plunger and forced with pressure through the filter candle—usually a replaceable cartridge—integrated in the device. The filter medium is made of a porous material such as fiberglass or ceramic, riddled with millions of tiny pores. Raw water passes along the outside of the filter candle and is then forced through the filter, removing fine particles including bacteria and single-celled pathogens in the process.

The filter cartridges are usually equipped with an integrated final filter stage with **activated charcoal** to remove some of the flavorings and any potential organic toxins.

During the pumping process, suspended particles in the water are retained on the outside of the filter, clogging its pores over time. Due to their relatively small filter surface, this can happen fairly quickly in very polluted water. I was once traveling in the Australian bush when my water supply was (once again) running low. I had no choice but to take water from an all-but-dried-up, dark green puddle soiled with animal dung. Even though my water filter was equipped with an additional prefilter, I could only produce around 0.1 liter (a scant half cup) of water before the filter became blocked. As a rule, individual and total capacities indicated by manufacturers usually apply to almost clean water.

Another problem, especially when the yield from very dirty raw water is small, is that with increasing filter pressure many users tend to force just a little bit more raw water through the filter. Since the generated pressure can be quite high, but most filters don't come with pressure relief valves, disease-causing pathogens are potentially forced around

A typical backpacking filter: Even though these devices are capable of turning raw water from virtually any source into safe drinking water, very dirty water should be prefiltered.



the filter into the drinking water, and small, invisible cracks can appear in the filter medium. To keep this from happening, the filter must be cleaned as soon as the pressure in the pump increases noticeably. To do this, it must be scrubbed in (preferably clean) water; however, this not only removes dirt particles but also a thin layer of the filter.

Yet this is a problem where there is only little water available or when the filter produces only small amounts of drinking water: The filter candle is cleaned in raw water, but depending on the model used, the outlet of a dismantled filter cartridge is liable to come into contact with contaminated water. With very pathogenic germs (such as cryptosporidia), this can be enough to cause severe diarrhea. It is therefore vital to prevent even a single drop of raw water coming into contact with the drinking-water side of a filter.

Some models are even designed in such a way that when the filter candle is removed, any (by now highly concentrated) dirty water remaining in the housing runs off along the drinking-water side. In this case, the filter must be flushed after reassembly with several pump thrusts of clean water.

The cleaning intervals can be extended by applying preparatory filter methods (see page 135). Drawing water from an infiltration well away from a polluted water source can also markedly increase the capacity of a filter.

Another important concern with backpacking filters is that they must be stored correctly. Leaving a filter unused in the backpack for a few days on a trek through the jungle allows all kinds of germs left in the cartridge from the previous filtration processes to multiply.

Mold, too, takes hold inside the filter and over time grows through the filter matrix. To prevent this from happening, the filter should be dried at every opportunity and boiled regularly.

Wet water filters are quickly destroyed by freezing temperatures. Due to its **anomaly**, water expands when frozen. The resulting pressure from the ice crystals at best bursts the filter candle. More problematic, however, is if hairline cracks are the only damage and go unnoticed. The filter—or at least the wet filter cartridge—has to be stored in such



The suction sieve on backpacking filters can be made more dense with a small sponge or a little cotton wool in order to extend the intervals between cleaning the filter cartridges.

[1,300 gallons]] stated by manufacturers can generally be considered as far too high when used with very dirty water.

When using backpacking water filters, the raw water should only be “slightly cloudy” (ca. 50 NTU). Even with “moderately cloudy” water (100 to 200 NTU), a water filter can become clogged after less than two liters. The prefilters of most common hiking filters are too porous, so it is imperative that any raw water that is more than just “slightly cloudy” be clarified beforehand.

If you know that you are likely to deal with cloudy water on your travels, you can improve the performance of the prefilter with a piece of kitchen sponge or micro-fiber cloth. While cleaning the prefilter is usually not a problem, there is always the risk of a bypass and contamination when cleaning the filter candle.

After a certain number of uses and cleaning cycles, a filter candle will either become terminally clogged

a way that it can't freeze en route. If that is not possible, the filter should be filled with a little salt water and then pumped until empty a few minutes later.

As mentioned, the filter capacity is limited by the actual pollution present in the water. Sufficient experience with various models, however, has taught me that the capacity information (sometimes over 5,000 liters

Good hiking filters have separate stages for filtration (right) and activated charcoal (left). In most cases, the **activated charcoal stage** is saturated long before the filter cartridge is used up.



or so worn (often they come with a gauge to determine when that is the case) that it can no longer fulfill its purpose.

Hiking filters are often combined with an activated charcoal step, which needs to be taken into account when considering the life span of a filter candle.

Hollow fiber filters



In recent years, hollow fiber filters of various sizes have been promoted as small filter miracles.

Their manufacturers claim they are lightweight, comparatively cheap, and with a pore width of 0.1 micrometers to retain not only bacteria but viruses, too (at least that's what they said in the beginning; see page 100), and that they have a service life of many thousands of liters of water. If clogged, they claim, they can easily be cleaned by back-flushing with a syringe or by washing in water.

The technology was borrowed from medicine—hundreds of hollow fibers encased in plastic allowing for the parallel filtering of water. However, professional use and experience with heavily polluted water in real-life situations have raised some serious issues. Due to the small filter surface, the hollow fibers clog after just a few centiliters (a few fluid ounces) of cloudy water with no more than 50 to 100 NTU.

What is more, the flow speed is very slow, since these filters don't feature a built-in pump. As a consequence, the water must be clarified thoroughly with a separate prefilter or through other preparatory methods.

Cleaning the filters is equally difficult. The back-flushing procedure is anything but simple and thorough. Colloids of various sizes become permanently lodged in the pores, further reducing the flow speed over time. They are also nearly impossible to dry properly. For storage, they need to be disinfected with chemicals, but large amounts or aggressive substances such as chlorine dioxide must be avoided, as they can damage the membrane. Yet most of them are not designed by the manufacturers to be disinfected, which is why, when “appropriately” stored in a backpack, they turn into virtual bioreactors.

Another problem is the hollow fibers themselves, which are liable to break during use and cleaning. This creates a bypass for raw water. In contrast to broken filter candles, this kind of damage is invisible.

There are many reports of users who contracted water-borne diseases after using these filters. Hollow fiber filters are—like Minisart filters—suitable as a backup in an unplanned emergency to treat a limited amount of drinking water. They are often promoted as a better alternative for professional backpacking filters—something they are definitely not.



European manufacturers now also offer simple hollow fiber filters, but they are more of a gimmick for very clear water than a reliable water treatment method.

Minisart filters



Minisart filters are small laboratory filter attachments for syringes. They are available in assorted diameters with different pore sizes, typically between 0.1 to 0.45 micrometers. In the laboratory, they are used for the sterile filtration of heat-sensitive solutions. Due to their small size, they are—like water purification tablets—an ideal constituent of a small emergency kit to be carried on the body at all times.

In addition to their small size and low weight, the great advantage of these filters is that the size of their pores is exactly defined and they really do not let any larger particles through. Thanks to their small filter surface, however, the capacity of these single-use filters is relatively limited. It is therefore advisable to only use pretreated water without any visible turbidity. With clear seawater, for example, a 0.3-micrometer filter with a diameter of around 3 centimeters (just over 1 inch) can filter more than 5 liters (over a gallon) of water. Even light turbidity, however, reduces the

capacity significantly, to less than 100 milliliters (half a cup).

Yet these filters are still of interest to us: In contrast to backpacking filters with their large tolerances, they don't run the risk of raw water bypassing the filter, and they are capable of producing sterile water for cleaning wounds and washing eyes. Use of the filter capsules requires a small syringe with which the water is *pressed* through the filter. When the filter is nearly saturated and the pressure increases, its capacity can be improved a little by *pulling* a small amount of water back through the filter; that water must then be discarded.

Charcoal filters

💧💧💧 1 You may already be familiar with activated charcoal from the filter in your fish tank or from the granules or tablets in your medicine cabinet. Carbon, the main component of activated charcoal, has a chemical property that is unique in our carbon-based world: It can form compounds with virtually any other element. This is the reason why organic chemistry—i.e., the chemistry of carbon—knows an infinite number of different substances, while there is a finite number of compound substances in inorganic chemistry.

Organic substances in the water or in the air such as bacterial toxins, colors, and tannins have a carbon-based structure and can easily be bound in activated charcoal. In

Syringe filters are tiny and lightweight. In an emergency, depending on the filter strength and raw water properties, they can generate between a few milliliters to several liters of practically sterile water.



addition, many bacterial pathogens and viruses are “trapped” on the surface of charcoal when their protein coats and sugars form a compound with the carbon. Dissolved salts and metals, however, are barely affected by charcoal filtration.

While commercial water filters, medicine, and chemical

detoxification processes rely on elaborately produced activated charcoal, in an emergency one can use ordinary charcoal. Even though the effect of carbon as a filter medium is undisputed, the effect of “normal” charcoal is repeatedly debated anew. Activated charcoal has a reactive “inner surface” of around a thousand square meters per gram. It may seem hard to believe, but ordinary charcoal, at best dampened down with water, has a surface of a hundred square meters per gram. That is, of course, significantly less than activated charcoal but still more than enough in the majority of cases. When producing drinking water, it is not normally necessary to remove large amounts of toxins (which is unlikely to be achieved with improvised methods anyway). What is required is to remove traces of undesired or hazardous substances such as dissolved detritus, residual pesticides, chlorine, and tannins that are either harmful to our health or that cause an unpleasant taste, odor, or discoloration. They usually occur in such small quantities that ordinary charcoal is perfectly capable of adsorbing them.

When suspecting the presence of bacterial or algal toxins in the only available source of water, repeated filtering with charcoal can significantly increase the purification effect, but on its own, charcoal filtering is not considered a reliable treatment method. Neither ordinary nor activated charcoal removes enough germs, nor can nitrogen compounds such as nitrate or nitrite be removed with this method.

You can filter through coal by adding a dense layer of coal either in a sediment filter or in a sealed container used like a drip filter. To purify water containing tannic acid or to remove the taste of chlorine after chemical sanitization, simply add a handful of pounded charcoal to a bottle of water and shake it vigorously for a few minutes. Let it settle and decant the water before consumption. When applying charcoal filtration as the last step in the purification process, a little residual coal dust in the water is harmless.

There is one fundamental thing to remember when using charcoal filtration stages (including in hiking filters): While there are usually only very small amounts of hazardous organic



Simple charcoal dampened down with water may not have the same huge adsorption surface as activated charcoal, but it is sufficient for the quantities of toxins to be expected in natural waters.

substances in the water, they accumulate in the carbon filter over time and remain concentrated there until the filter is saturated.

When filtering water with a high tannin content through an older, well-used carbon filter, for example, the tannins in the water can displace the toxins “stored” in the charcoal, contaminating the filtered water with large amounts of all kinds of toxins. While they are rarely harmful in natural concentrations, they can lead to acute poisoning in an over-saturated carbon filter.

For that reason, and to prevent a potential contamination of the charcoal particles, improvised carbon filters should not be used for more than three or four days. As it is fairly easy to produce the source material, it is advisable to make a new coal filter each day.

Backpacking filters with an integrated activated charcoal step should be replaced according to the manufacturer’s information. Ideally use filters with a separate coal step that can be replaced independently of the filter candle.

Boiling

💧💧💧 I don’t know of any other aspect of drinking water purification that is subject to as much speculation in debates between nonprofessionals as the simple process of boiling water. Numerous unconfirmed messages, recycled over the years, are being amalgamated with expert biological and chemical information and creating a very confused set of information.

I would like to briefly list the important biological and physical facts on the subject of boiling water:

1. Ordinary drinking water is never sterile, and it doesn't have to be. We disinfect, or sanitize, drinking water by removing or destroying any disease-causing germs. There are many (nonpathogenic) microorganisms and dormant stages that endure brief boiling at high temperatures just as easily as half an hour's simmering.
2. Human pathogenic germs belong almost *exclusively* to the group of mesophilic germs (their optimal environmental temperature is equal to our body temperature). Mesophilic germs are adapted to the temperatures naturally occurring in mammals and during propagation (for example, in the air). They can survive frost but in some cases die at temperatures of 107°F (42°C) (fever temperature).
3. Around the world, potentially highly infectious foods (milk, pork, natural sausage casings made from animal intestines, top-dressed vegetables, etc.) are consumed after being heated. Contaminated food usually contains many times the amount of potential pathogen concentrations of raw water.
4. When preparing food safely, the aim is to achieve a core temperature of around 170 to 180°F (75 to 85°C). In microscopically small particles, this core temperature is reached within fractions of a second, which is why raw milk (containing cryptosporidia, *E. coli*, etc.) is pasteurized for only fifteen seconds at 161°F (71.7°C).
5. For each additional 300 meters (1,000 feet) in altitude, the boiling point of water reduces by around 2°F (1°C). At 4,500 meters (14,000 feet) above sea level, water has a boiling point of around 185°F (85°C). At this altitude, clean snow or meltwater can be collected almost anywhere in the world.

Briefly boiling even contaminated water can always be considered a reliable treatment method. Even heating it to

180°F (85°C) kills practically all living cells. Single-celled parasites, otherwise very robust, are especially heat-sensitive. Common technical disinfection (not sterilization) in bottling plants occurs at 158°F (70°C). Heat-resistant bacteria and spores, however, survive even being boiled for an hour.

In debates about how long water should be boiled for, advocates of the “prolonged-boiling method” have only ever hinted vaguely that there are germs that survive this kind of treatment. *Which specific pathogenic*, and in the relevant numbers *infectious*, germs they are referring to has still not been explained.

Note:

Sterilization

Sterilizing a substance kills *all* present microorganisms (disease-causing or not), including their dormant stages. Sterile solutions are used for washing wounds or in infusions. Even the best drinking water is never sterile.

Disinfection

Disinfecting a substance either kills or *inactivates* all *active* pathogens. In the context of drinking water, this specifically means killing all pathogens that are harmful to humans when ingested. The vast majority of all bacteria and microorganisms are not infectious via the gastrointestinal tract and therefore do not need to be removed (clostridia, for example, are very harmful in wounds but harmless in the gut).

The aim of heat treatment is to purify drinking water to such a degree that it does not make “normal people” sick—the idea is not to produce a sterile infusion solution. Boiling water for longer periods of time takes a lot of energy and water (which is lost as steam). Heating to boiling point is more than enough. When working with improvised methods, keeping



Bringing one liter of water to a boil at moderate altitudes and cooling it down again means that the water will have a temperature of over 176°F (80°C) for more than ten minutes.

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water at a boil for more than a minute is hardly feasible. The only thing to remember is that

very cloudy water should be clarified with heat precipitation and subsequent decanting before boiling.

## Solar heat



Maybe you have made this mistake on a summer evening: You go to water the plants in your garden without considering the fact that the filled hose has been lying in the blazing sun all day. The result in your flower beds probably resembled blanched vegetables. The solar energy that hits the ground on a summer day equals around a thousand watts per square meter (a hundred watts per square foot). Even if only a fraction of that is absorbed by a light-colored hose, the temperature of the hose and the water it contains rises significantly. This effect is put to good use to heat industrial water in countries with a lot of sunshine. Inside the black sun collectors, temperatures can reach several hundred degrees.

With simple heat collectors where water flows passively through a thermosiphon directly connected to a water storage container, the water current is created by the temperature difference. The water is briefly heated to just below boiling point and is thus considered boiled. In warm regions, the same principle can be used to run improvised small water supply systems that do without a backflow of the heated water.



Water in an improvised container, boiled with the use of hot stones: Even with a lot of practice, you will struggle to keep water at a boil for ten minutes in such a system. It would be a waste of time, energy, and resources.

With the aid of a simple thin black or blackened (for example, with soot) plastic hose and bottle, a solar collector can be assembled that can heat the water flowing through it to around 190°F (90°C). Since this doesn't happen very fast even in hot regions, the flow speed is limited to a few drops per minute. The water dripping into the collecting container will be very hot and can be drunk once cooled.

As the water remains in the hose for more than ten minutes, the germ count in the water is reduced considerably, even at temperatures of 140°F (60°C). A person's entire daily need can be met by running this process continuously. Remember, though, that effective heat absorption relies on a dark-colored hose, a small diameter of the hose, and a cloudless sky. The hose should be very hot to the touch if you want to drink the water without further treatment.

## UV radiation

Many germs and some protozoa can endure temperatures ranging from far below freezing to significantly above the boiling point of water (even though the latter play no part in causing waterborne diseases).

Others can survive dried-up for more than a hundred years and still be infectious when they wake up. One such example is anthrax spores (*Bacillus anthracis*), which can cause problems when disused tanning pits are excavated. But there is one thing few pathogens endure, and that is direct sunlight.

Indeed, the earth is subjected to a constant bombardment of solar particles—i.e., electromagnetic radiation. Many of the high-energy particles are capable of

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A water heater made from five meters of thin black hose and a reflector: The temperature inside the hose can reach up to 195°F (90°C).



penetrating cells and causing severe damage to the genetic material in the form of double-strand breaks. Earth's magnetic field and ozone layer protect against some of this radiation, but still fatal light storms are raging on the earth's surface.

The only organisms able to survive this assault are those that can either repair the damage caused by light or hide from the sun behind pigmentation. As a result, the vast majority of dry surfaces exposed to direct sunlight are in fact sterile. We, too, feel this deadly danger after a short time spent in the direct sun: regardless of the temperature, sunbathing in the spring can cause sunburn, too.

The main culprit of this damaging effect of sunlight is its ultraviolet component. This (invisible) form of radiation is not dissimilar to X-rays.

Just like radioactive radiation, UV light is employed to kill germs in laboratories, technical processes, and water purification treatment. I'm not talking about the famous black light popular in nightclubs but "hard" UV light that can cause a severe burning of the skin.

Electric UV radiation



Some disinfection lamps on the market for laboratories and food manufacturers are surprisingly effective. Exposing surfaces or solutions contaminated with bacteria briefly to their light eliminates nearly all living cells. These lamps are available with 12-volt, 110-volt, and 230-volt connections for treating water, for example, in the car, at home, or in combination with small water supply systems in disaster areas. These technical devices are reliable but large and therefore unsuitable for water treatment on hiking trips or expeditions.

Sterilization pens, however, are developed specifically for use "on the go"; they are convenient and, weighing only around seven ounces (two hundred grams), easy to carry. The advantage of their low weight compared to backpacking filters, however, is quickly offset by the large number of batteries needed by the device.

The handheld sticks are immersed in a container of contaminated water. The UVC radiation they give off when switched on is aggressive, but it can't exit the plastic container. The radiation intensity is more than sufficient to kill any microorganisms, but light cannot penetrate optically dense media and is absorbed by colored particles such as chlorophyll. The treatment time of less than a minute is quite short; as many suspended particles as possible must be removed from the water (i.e., it must have no visible cloudiness) to ensure a reliable effect.

A safeguarding feature in these lamps guarantees that they can only be switched on in water to prevent burning of the skin and damage to the eyes.

As simple as these tools seem, they have one significant downside: There are dozens of reports of unreliable pens. Sooner or later these devices stop working, especially in developing countries where water purification is important and where the required high-performance batteries are often unavailable.

Now, new models are available that can be used with off-the-shelf batteries. Another innovation on the market is a small type with an integrated lithium battery that can be recharged via a USB cable from a mobile solar panel or car cigarette lighter—ideal for long trips.

Unfortunately, all UV devices share the same serious constructional weakness—the gas-filled tubes and the lamp housing are made of glass. And even though there now appear to be fewer product defects and failures than a few years ago, I personally would not take them as my only water treatment option on expeditions or long-distance travels.

Battery-operated UV generators do the job, but sensitive electrical devices are always a risk on expeditions.



SODIS



A different UV source, a different picture: The sun shines regardless of whether batteries are available or not. Even better in terms of reliability, the invisible UV rays hit the earth even on a cloudy day. In the 1980s, scientists at the American University of Beirut developed the practical application of solar water disinfection (SODIS), which is simple to use, safe, and reliable. SODIS is the ideal technology for converting large amounts of contaminated raw water into safe drinking water. All that is needed is one or more containers made from clear glass, transparent PET, or similar material. The important thing is that the material must let through the sun's UVA light, which is required for this method to work. The glass or plastic must therefore not be colored, scratched, or otherwise dulled. In addition, plastic containers must not be made from PVC. Recycled glass, which partly consists of window glass, is also unsuitable for SODIS, as window glass is impermeable to UV light.

The most reliable option is a container made of plastic like the ubiquitous single-use drink bottles that are unfortunately (and sometimes fortunately) found on beaches and roadsides anywhere in the world. Clear hydration bladders may be used, too. The material they are made of may block some of the light from the UV spectrum, but their flat construction allows enough UV light to pass through and disinfect the water to a reliable degree.

When disinfecting water with the SODIS method, don't fill the bottle to the top. The larger the volume, the deeper the light must penetrate and hence the fewer fine particles can be suspended in the water. For best results, use a 1.5-liter bottle (or larger) that has been cleaned and has all labels and sticky residue removed. As many particles as possible must be separated from the raw water before pouring it into the bottle. Water must be "without visible cloudiness" for SODIS to work properly, otherwise it is possible that individual germs can hide from the UV light in the "shade." The same applies for discoloration. Anything that exceeds a slight discoloration should be removed with a charcoal filter, if possible.

According to the Swiss Federal Institute of Aquatic Science and Technology (EAWAG*), shaking air into the water before SODIS to produce free radicals, which used to be recommended, is not necessary. A more important factor, apart from UV light, is temperature; it is vital that the sun heat the water to at least 122°F (50°C) for it to be disinfected properly.

The radiation kills all relevant disease-causing pathogens, even those that are increasingly resistant to chemical disinfectants. The treatment duration depends on the weather:

Condition	Treatment duration
Clear sky with only a few clouds	Six to ten hours
Mostly cloudy	Two to three days
Overcast and gloomy	Reliable disinfection with sodis not possible; use an alternative method

Unfortunately, the application of SODIS in disaster zones and developing countries has not been a resounding success. While the method is suitable for making contaminated raw water drinkable, outbreaks of life-threatening diseases have barely declined.

Having said that, it is likely that the method is being used with scratched or dull bottles and that the raw water being used is too cloudy. In order to seriously contain life-threatening diseases, a profound change in behavior is required: No swimming or washing food in severely contaminated water, and no sipping “just a little” raw water here and there.

This evaluation of SODIS shows how important it is to understand the different methods in order to apply them correctly.

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In the sun, clarified water is made drinkable within a few hours of exposure to UV light.



\* Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung, und Gewässerschutz

For example, it has been rumored that SODIS only works between the equator and the thirty-fifth parallel, but that is incorrect. It is true that EAWAG highlights the following: Most developing countries are located between the thirty-fifth parallel north and the thirty-fifth parallel south, and they are best positioned for reliable sunshine, as the best conditions prevail between the fifteenth and the thirty-fifth parallels. Near the equator (too many clouds) and in temperate climates in the winter, solar radiation reduces, and with it the effectiveness of SODIS. EAWAG scientists further explain that a total irradiation of five hundred watts per square meter is sufficient to ensure complete disinfection after six hours. Even in winter, places like the northern USA and southern Canada see solar irradiation of this magnitude on a clear day—in the summer it is twice as much.

### *SODIS for filter materials*

UV radiation is not only deadly for germs in water; it also has the same effect on pathogens on dry surfaces. As a result, filter material can also be disinfected with sunlight. This is especially interesting when using sand from a contaminated body of water, or when filter media need to be cleaned after a long time in use.



SODIS won't work like this: The reflector may be an advantage, but the bottle on the left is milky and scratched due to age and/or transportation-related damage. The water in the bottle on the right is cloudy and contains solid particles, both of which interfere with SODIS.

On a dry surface, it often only takes mere fractions of a second for bacteria to be destroyed. However, the material must be dried in the sun beforehand and then spread out as thinly as possible. It must be turned constantly and irradiated, ideally at midday, for half an hour. Larger amounts are best treated in batches. This method does not work for netlike structures, as it cannot be guaranteed that the sunlight will reach all places.

## Chemical disinfection

There are so many different tablets, powders, and drops available on the market that it is almost impossible to describe them all here. They are largely based on the oxidizing and cell-destroying effect of chlorine compounds, iodine, halazones, and other similarly aggressive chemicals. When comparing their inherent risks against waterborne diseases, the approved agents are generally deemed to have no ill effect on human health, provided the recommended dosage is adhered to. The disinfectants and other ingredients are normally neutralized by stomach acid and dietary proteins.



Solid substances can also be disinfected with sunlight; they must be dry and turned regularly in the sun.

An important factor is the indicated application times; it is vital that they are adhered to, especially when suspecting the presence of cryptosporidia, entamoeba, or giardia in the water. If the water is very cold, the duration may need to be extended for some agents. Cloudy water, and water with a high tannin content, must be clarified or decolorized with charcoal before treatment with most chemical disinfectants, to prevent the formation of irritant chlorine compounds and limitation of the sanitizing effect.

In the water, the chlorine-based disinfectants decompose into hypochlorous acid and, later, reactive oxygen, both of which are responsible for the germicidal effect. Following contact with foreign substances in the water, these aggressive compounds are “deactivated”—i.e., they are converted into harmless substances such as table salt. If the concentration of disinfectants in the water is too high, too many reactive “particles” may remain in the drinking water, which can lead to irritation of the skin. In cloudy water or water containing organic substances, the treatment agents react with

those particles instead of the germs. This goes to highlight the importance of proper dosage and appropriate preparation of raw water.

Furthermore, it is essential that the correct agents be used when disinfecting water. While combination preparations based on hypochlorite and silver ions, for example, may be used to disinfect and preserve water, preparations based on a single active agent such as silver ions are suitable only for the *preservation* of clean water and for the disinfection of *clean* and *clear* raw water with a very low germ content and *without* any single-celled parasites.

If you don't like the harmless taste of iodine or chlorine in the treated water, this can be removed with charcoal filtration.

Sanitizing drinking water with the aid of "a few crystals" of potassium permanganate is nowadays considered anachronistic. While the substance is indeed capable of disinfecting water, getting the dosage right is incomparably more difficult, and handling the substance is significantly more hazardous and harmful to our health.

## Iodine



Around the world, iodine and its compounds are used to chemically treat drinking water. Iodine in its elemental form as crystals or in the form of soluble compounds has its advantages, but it is not a simple one-size-fits-all solution.

The most important advantage is surely its ubiquity: Whether in crystal form or as an antiseptic wound solution, it is available practically anywhere, even in rural disaster zones. It is also very inexpensive, making it ideal for sanitizing large volumes of water. In addition, its chemical structure is very stable—it does not spontaneously degrade like many chlorine compounds—and it is significantly less harmful than comparable crystalline compounds such as potassium permanganate.

And yet there are downsides, least of which is its unpleasant taste. Iodine is needed by the body and is in fact an essential dietary mineral; however, this means that prolonged disinfection with the trace element leads to increased absorption

by the body, which can affect thyroid function. Infants, pregnant women, and the sick should therefore avoid consuming additional iodine. On the other hand, excess iodine in water contaminated with radioactive isotopes can inhibit the absorption of harmful iodine-131.

Getting the dosage right isn't always easy, either, as its solubility in water is low and variable dependent on the temperature. The solution should be mixed at around 70°F (20°C).

Low solubility, however, also makes it very efficient: Just a few grams of elemental iodine are required to make a sanitizing solution for several thousand gallons of water without needing to change the process in any way. This is another reason why iodine is a particularly suitable agent for the purification of water reserves or in stationary water treatment in disaster zones.

Regarding water stores, however, it is worth knowing that iodine “evaporates” when exposed to the air (i.e., its crystals sublime), which is why elemental iodine should always be kept covered with water in a sealed container. Laboratory screw cap jars with a scale printed on the side are ideally suited for this purpose. When storing iodine crystals in water, a saturated solution with 0.0003 grams of iodine per milliliter forms in the water (at room temperature), no matter how much liquid is added on top of the iodine crystals. This allows for a relatively accurate dosage: A dosage of four parts per million (ppm) is usually deemed to be sufficient for the disinfection of drinking water, which basically means adding 0.004 grams of iodine to each liter of water, or around thirteen milliliters of the saturated parent solution. Accordingly, a metric ton of water can be disinfected with 4 grams of elemental iodine.



A few iodine crystals suffice to make a sanitizing solution for many hundreds of liters (over a hundred gallons) of water.

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Remember, though, that iodine compounds react similarly, but at lower temperatures considerably more slowly, to chlorine compounds. While twenty-five minutes is sufficient at room temperature, the application time doubles with each drop of ten kelvin in temperature.

Tablets with fast-dissolving iodine compounds are more expensive than elemental iodine, but they work the same way, and you just need to follow the manufacturer's instructions. Unfortunately, however, in many regions, neither iodine compounds nor elemental iodine is legally permitted as a treatment method for drinking water.

Excess iodine can be separated from the water with a carbon filter or with a "flavor neutralizer" (with commercial two-component iodine products, it is always the second dose), usually plain old vitamin C. The ascorbic acid converts the iodine solutes in the water into flavor-neutral iodide, which at the same time neutralizes its ability to react and to disinfect, and hence to preserve. When water treated with iodine is to be stored, it can be laced with a pinch of vitamin C immediately before consumption.

## Chlorine dioxide



Highly reactive chlorine dioxide is employed when treating large amounts of water in a stationary treatment setup—and, infrequently, as part of a two-component system when backpacking. The chlorine compound is so effective that it is considered to be a particularly reliable water sanitizing agent.

Unfortunately, its reactivity is so high that the substance decomposes quite quickly on its own, and wrong dosages or incorrect production can have substantial health implications.

The manufacturing process of chlorine dioxide is often based on the reaction between sodium chloride and other compounds as well as an acid in the "chlorite acid process." This reaction is likely to produce highly poisonous and explosive gases as a side effect—especially if it is not known what other substances may be dissolved in the raw water or in the

parent solution. For the process to work properly, the conditions must be precisely controlled.

The apparent advantage of these solutions is their low cost. Unfortunately, however, commercial chlorite solutions are often blended with large amounts of chlorates, which can lead to undesired reaction by-products. Products approved for water treatment by the end user (such as Aquamira), on the other hand, are comparatively expensive.

Chlorine dioxide is hard to dispense precisely in small doses, especially when the concentrated parent solution originates from some dubious internet pharmacy.

When ingested, large amounts of incorrectly manufactured or dosed—and therefore unconverted—chlorites, chlorates, or chlorine dioxide can kill blood cells and severely damage internal organs. What's more, the products created by mixing with acid are so unstable that in the calculated dose they are only usable for a short period of time, and in highly concentrated form they attack plastics and metals, which must be taken into consideration when disinfecting water filters.

While large industrial water treatment plants may well be able to handle this highly poisonous substance, its hazardous nature makes it less suitable for the individual consumer, especially when there are a number of compounds, such as relatively stable hypochlorites, that can be dosed more accurately, convert immediately when used, and present a considerably lower risk potential.

## Hypochlorites



Hypochlorite solutions are a tried and tested option for sanitizing water. And while highly concentrated hypochlorite is just as dangerous as chlorine dioxide, there are precisely dosed, long-lasting preparations that can be applied drop by drop. Tablets and sodium hypochlorite are commercially available as a 2 percent solution, so the dosage instructions are easy to follow: For example, one tablet per liter or per ten liters, or three drops of the solution per liter. As described above, these agents are available as combination preparations

with added silver compounds, which help preserve the water by delaying recontamination of the water for an additional six months or so—useful when setting up water stores.

These preparations can be used sparingly and are comparatively inexpensive, but the number of manufacturers has fallen



Preparations with silver ions but without hypochlorite are suitable for preserving and sanitizing only mildly contaminated water. For very polluted water, you may need to use preparations labeled “Forte.”

over the past years. Katadyn’s Micropur Forte is probably the most commonly used product today.

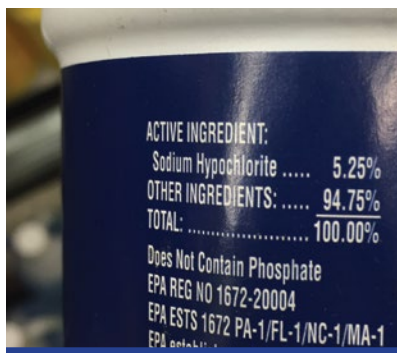
When large amounts of a hypochlorite solution are required—for example, when treating drinking water in storage cisterns or in stationary treatment systems—commercial bleach products that are ordinarily used as cleaning agents (typically a stabilized 2 to 4 percent solution) or as disinfectants for storage tanks and swimming pools (usually 13 to 15 percent) can be applied. Check the products’ safety data sheets: Besides sodium hypochlorite and sodium carbonate, they should not contain any additives such as surfactants or fragrances and should ideally be approved for the disinfection of food and kitchen utensils.

The dosage of a 2 to 4 percent solution is similar to that of water decontamination drops, one to two drops per liter of water. Products with higher concentrations must be handled very carefully and are only suitable for disinfecting large amounts of water. They typically start with one to three drops per ten liters (two and a half gallons), or the dosage is increased slowly until a slight chlorine smell can be detected in the treated water thirty minutes later.

These products are usually prohibited for the purpose of generating drinking water, but in an emergency they are a much less dangerous option than experimenting at home with mixing your own highly concentrated, instable chlorine dioxide solutions.

We know from experience that swallowing chlorinated water from a swimming pool does us no harm, provided the correct dosage (usually of ozone or hypochlorite) is applied.

When forced to use hypochlorite solutions of higher concentrations in relevant risk areas, you can ensure that you have applied the correct dosage by using diagnostic dipsticks. With the right concentration applied, treated water will contain relatively little residual active chlorine after thirty minutes.



Only in an emergency: In many countries, stable, additive-free bleach products can be obtained from any corner store. They come in handy when the water supply has suffered a total collapse.

### MOS (mixed oxidant solution)



A very interesting principle for emergencies on trips and when not far from the civilized world is the production of mixed oxidant solution (MOS). Applying electrolysis to a brine produces disinfecting substances. MOS generators specifically designed for this purpose have been used successfully in the field by the US Armed Forces for several years. The advantage of MOS is its very aggressive disinfecting power even at low concentrations. The downside is that it always requires a power source (in form of a main adaptor, car battery, or lithium cell).

MOS generators have a small chamber where table salt is dissolved in water (in effect creating a saturated solution). A voltage is then applied to this saline via two electrodes.

During this chlor-alkali process, various chlorine compounds, sodium hydroxide (lye), and hydrogen are formed. Commercially available MOS devices have special electrodes. When using simple copper electrodes from ordinary electronic cables, some of the copper dissolves in the water, which often leads to the formation of oxyhydrogen instead of the desired chlorine compounds.

Experiments with a shot glass full of concentrated brine, a cell phone battery, some titanium cutlery, or pencil lead as electrodes produced enough MOS for disinfecting purposes. You should note, however, that this improvised chlor-alkali electrolysis can cause unhealthy by-products to form and that the power source may get damaged. If you are stuck in a disaster zone for some time and exposed to the serious threat of a bacterial infection, however, the risks of these unknown by-products are usually comparatively minor. When experimenting with various materials in an emergency, watch out for the typical odor of chlorine. The reaction should continue until either the solution has an *intense* chlorine smell, or until the bubbles stop forming at the electrodes (some electrodes tend to oxidize and must be scraped free frequently). The water should not discolor too much. If it does, you need to use a different electrode material. The process must not be conducted near any sources of fire or sparks to prevent any resulting oxyhydrogen from igniting.

Add a few drops of this solution to raw water, shake, and test for chlorine odor. If the water smells *slightly* of chlorine, leave the solution to work for an hour. If it doesn't, add a few more drops and repeat. At the end, the water should taste slightly of "swimming pool."

This improvised method of sanitizing water is in fact capable of disinfecting water 100 percent, but because of the potentially hazardous substances involved, it should only be used in an emergency.

## Desalination

### Reverse osmosis



Imagine placing a strawberry in some sugar. What happens? Liquid begins to ooze from the fruit. The reason? Osmosis. We have already mentioned the terms *osmosis* and *osmotic pressure* in previous chapters; in order to understand reverse osmosis, we need to look more closely at the process of osmosis.

All cells are enclosed by a membrane, and these membranes have a particular property: They are semipermeable. They let small particles through, but larger ones are kept in—or out. The most important small molecule that can slip through the net is water. Solute minerals, cell components, and proteins, however, are unable to escape. Another important property that goes hand in hand with semipermeability is osmotic potential. Osmotically active particles (such as salt in seawater) “attract” water. If salt is added to water, the molecules in the solution start to migrate until all the salt particles are spread evenly.

When a dish split into two halves by a semipermeable membrane is filled with salt water on one side and fresh water on the other, both solutions “want” to mix until they have the same saline concentration. Since only water can get through the membrane, the relative water volumes have to adapt to achieve an osmotic balance.

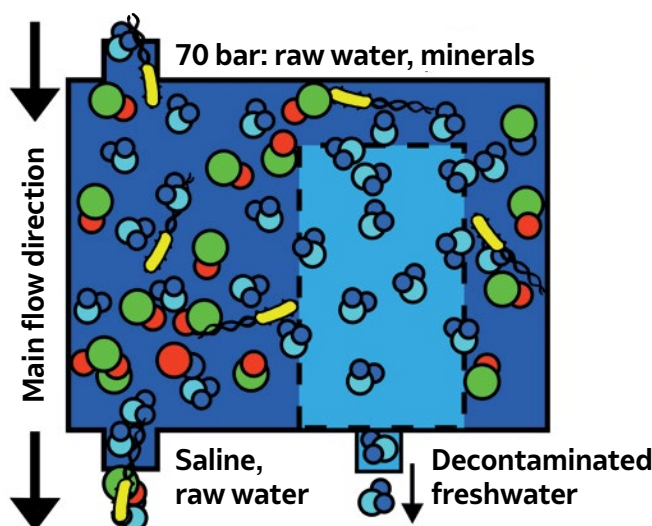
In fact, fresh water will migrate through the membrane into the saltwater compartment until the increasingly concentrating minerals in the fresh water have achieved the same osmolarity as the increasingly diluted salt water. This results in a marked difference in water levels.

This is the principle behind desalination with reverse osmosis. A cylinder sealed with a semipermeable membrane acts like a filter: Filled with sea water, it retains the salt, allowing only fresh water to seep out. It does require enormous pressure, though. The higher the salt content, the greater the pressure exerted on the membrane has to be to

achieve pure fresh water. Desalinating seawater requires a pressure of around 70 bars (1,000 psi, equal to around 700 meters [2,300 feet] below sea level; a car tire is typically pressurized to between 2 and 2.5 bars [30 and 35 psi]).

With all the commitment in the world, you will not be able to create the necessary pressure with a pump whittled from hazel wood, especially since you will need a suitable membrane, too. Reverse osmosis pumps for emergencies and travelers have been available for a few years, but it is worth noting that these inexpensive devices originally designed for the production of clean water in fish tanks are merely able to separate small mineral residues from fresh water (the pumps produce no more than 2 to 5 bars [30 to 70 psi].)

Since desalinating seawater requires high pressure, appropriate devices are both heavy and relatively expensive. The Swiss manufacturer Katadyn offers suitable desalinators for emergencies and travelers at prices ranging from \$1,200 (Survivor 06) to \$2,400 (Survivor 35). With manual



The principle behind reverse osmosis: Raw water is forced past a membrane film under high pressure. Only the small water molecules can pass through the membrane, while mineral solutes, chemical compounds, and disease-causing pathogens are “filtered” out. An inbuilt outflow for the concentrated saline prevents the membrane from clogging up and from breaking under the enormous pressure.

A reverse osmosis pump allows you to travel independently and for long distances along salt-water shorelines.

use, they generate, depending on the model, between half a liter and four liters of drinkable water per hour. This may seem like very little, but in an emergency this is more than enough with normal activity to cover the daily need.

Especially on expeditions and on trips to regions with extensive brackish water zones (river deltas, shorelines), as well as on boating and kayaking trips in seawater, a mobile reverse osmosis pump can be a vital piece of equipment to safeguard survival.

Due to their high price, these devices could be regarded as something only for the pros among extreme travelers. But considering how much money some people are willing to spend on a smartphone made in East Asia, and how irrelevant that is for survival in contrast to drinking water, the costs are quickly put into perspective.

## Functionality

The operation of reverse osmosis pumps is relatively intuitive, yet the following points must be noted.

- The integral membrane is very sensitive; it must not be allowed to dry out, and once in use it must be used for ten minutes or treated with a preservative every day. Also, the effort required is substantial, especially when the seawater has a particularly high salinity.
- Except for the membrane, these emergency devices are pleasantly robust. Immediately before their first use, the membrane must be cleansed of any residual preservatives by pumping for a few minutes and discarding the generated fresh water.





- The reverse osmosis process produces a concentrated brine that is discharged from the pump via a hose. This can be a problem when you are pumping salt water directly from a tank. With every thrust of the pump, the concentration of the water increases slightly until the pressure rises noticeably. When water is taken from a sealed container, it is important that the brine be discharged to the side and not allowed to reenter the raw water in the tank.

It is worth noting that because the *vast majority* of the water sucked into the pump leaves the device as concentrated brine, *for every volume of drinking water, you need ten to fifteen times as much saline raw water*. This is of particular importance when salt water is collected and carried as raw water. In order to produce a daily requirement's worth, you would need to carry at least fifty liters (thirteen gallons) of salt water with you. Much better to desalinate and preserve the water on-site.

On boating trips at sea, the water intake and discharge hoses can be hung over the side directly into the water.

Reverse osmosis is so efficient that it not only retains and discharges the tiny dissolved salt molecules but also the vast majority of other dissolved substances such as heavy metals and minerals as well as *all* particle components (bacteria, viruses, and proteins). Consequently, in cloudy water the mesh can quickly become blocked and *cannot be reactivated* en route. Even slightly cloudy water must be prefiltered or treated with heat precipitation beforehand.

Reverse osmosis is also a suitable and reliable method for making concentrated urine and brackish or contaminated fresh water safe to drink, even if that is not its main purpose.

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Within three minutes, the Survivor 06 can turn 1.5 liters of seawater from the Mediterranean Sea into around 1.45 liters saline unfit for consumption (left) and 50 milliliters drinking water (right; colored red).

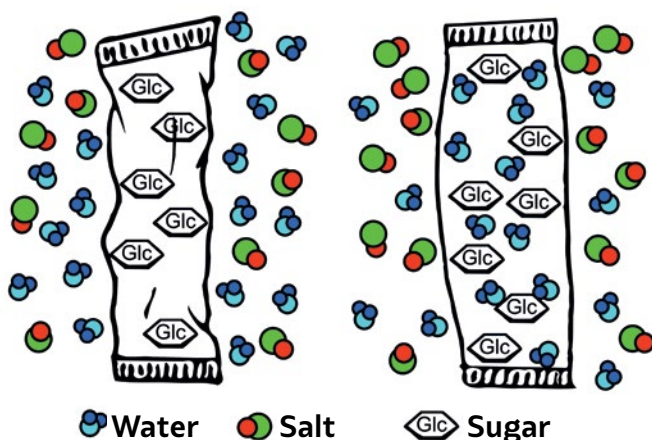


## Passive Osmosis



Less expensive than a reverse osmosis pump is a passive osmosis device, which makes use of the fact that a sufficient amount of sugar can create an osmotic counterpotential in a membrane that attracts water. In contrast to salt, sugar is quickly converted, burned, or stored by the body without unduly burdening the fluid balance. A piece of dialysis tubing is filled with a dry, sugar-based mixture. This is placed into salt water, where the water molecules are sucked through the membrane into the tubing. The salt remains on the outside of the membrane. The water is sucked into the tubing for around five hours until the osmotic potential is balanced.

Unfortunately, the system is ill suited to producing serviceable amounts of water. The amount that can be generated within five hours is up to half a liter. Typical total capacities are around four liters (a gallon). In an emergency, however, that may be enough to bridge a few days. Since several hundred grams (or several ounces) of granulated sugar are required to make a few liters (a gallon or so) of drinking water solution (the manufacturers call it “sports drink”), it makes more sense to carry a reverse osmosis pump or a number of sealed drinking water rations in an emergency kit or lifeboat.



The principle behind passive osmosis: The osmotic potential of sugar causes water molecules to migrate across the membrane. It makes more sense to carry drinking water reserves.

## Distillation

While the treatment methods described here so far largely mechanically remove or chemically destroy and deactivate harmful pollutants, distillation is the only other method besides reverse osmosis that produces totally pure water. In distillation, the chemical compound “water” is separated into its components with different boiling temperatures.

Distilling water is a considerably simpler process than distilling, say, whiskey. Whereas the individual components of mash (fusel oil, methanol, ethanol, water) have boiling temperatures ranging from 160°F to 212°F (70°C to 100°C), requiring the temperature during the distillation process to be precisely monitored, the picture looks quite different for the distillation of water: Water evaporates at around 212°F (100°C), but the minerals precipitating or crystallizing in the boiling process evaporate mostly at temperatures significantly above 2,000°F (1,000°C).

We can therefore safely assume that no salts or minerals will evaporate when boiling seawater. But what about potential toxins in seriously polluted saltwater or freshwater sources?

Some potentially toxic hydrocarbons that can enter the water with gasoline or oil may in theory still be present in the distilled water. It is therefore vital to assess first of all what substances are likely to be contaminating the raw water.

An improvised but efficient distillation system: Salt water is vaporized in a pressure cooker camping pot and then channeled via a heatproof PTFE tube into a plastic condensing coil.



Fuel is a likely suspect in disaster areas, following floods, storms, and so on, or whenever there is a distinct smell that points to oil, gasoline, or other substances in the water.

During a project in Australia, for example, I once found that several natural water sources (intended watering holes) had been rendered unfit for consumption by high concentrations

of highly poisonous hydrogen sulfide.

Merely distilling raw water contaminated with hydrogen sulfide or gasoline would transfer large parts of the toxins into the distillate (the distilled water). The only way to prevent this from happening is to keep



The water in the cooling unit must be replaced regularly; raw water or salt water may be used for this purpose.

the solution at just below boiling point for some time. This allows the more soluble substances to evaporate without wasting too much energy or water.

A further problem lies in the fact that when water is heated, the carbon dioxide—contained in nearly all natural sources—evaporates and precipitates as limescale in the pan. Unfortunately, some toxic substances present in the solution can deposit in the limescale. If the water boiling on the fire evaporates *completely*, the layer of limescale at the bottom can easily reach temperatures exceeding 1,000°F (500°C)—enough to vaporize some of the nonvolatile substances. This is why the process of distilling very polluted water should be stopped while there is still water in the pan, and the pan should be washed and ideally scraped out before reuse. A growing layer of limescale on the bottom of the pan inhibits the transfer of heat from the cooker to the water and therefore makes it more likely for aluminum pans and bottles to burn.

The particular challenge of distillation is that water needs a lot of energy to evaporate, which in turn needs to be dissipated from the steam in order to return it to its liquid form.

In the absence of suitable material to build a still with a cooling unit, raw or salt water can be brought to a boil in a pan, which is then removed from the cooker and covered with a plastic sheet or placed inside a closed tent. (Obviously, do not use the cooker inside the tent—there is a risk of carbon monoxide poisoning!)

### Energy requirement for distillation

| Fuel type      | Lower heating value | Minimum fuel requirement |
|----------------|---------------------|--------------------------|
| Gasoline stove | 40,000 kJ / kg      | 240 g                    |
| Gas stove      | 45,000 kJ / kg      | 200 g                    |
| Spirit stove   | 26,000 kJ / kg      | 360 g                    |
| Firewood       | 10,000 kJ / kg      | 1,000 g                  |

Fuel required to vaporize one kilogram of water with an assumed (ideal) heating efficiency of 25 percent.

The large surface of the sheet or tent wall facilitates heat dissipation, and the steam condenses. This condensation can be collected like dew with a cloth or towel. With the benefit of abundant fuel and raw water, the water can be boiled above a fire in a pan covered with a piece of cloth. The steam collecting in the cloth can be wrung out as water.

#### Fuel requirement

Vaporizing one kilogram of water with a temperature of 77°F (25°C) at sea level requires energy for bringing the water to a boil and then for keeping it at a boil until it has evaporated. Heating 1 liter of water by one kelvin requires 4,200 joules, or 1,000 gram calories (1 calorie). Bringing water at 77°F (25°C) to a boil—i.e., raising its temperature by 75 kelvin—therefore requires 4,200 joules × 75 kelvin, which equals 315 kilojoules, or 75 calories.

To then completely vaporize the entire kilogram of water takes an additional 2,088 kilojoules (500 calories). This large amount of energy is needed to break up the internal forces between the individual water molecules in their liquid state and would be sufficient to bring more than 6.5 liters (1.75 gallons) of water at 77°F (25°C) to a boil (we will need this value again a bit further on).

The total energy required to vaporize one liter of water therefore equals 315 kilojoules + 2,088 kilojoules = ca. 2,400 kilojoules, or 573 calories.

The techniques described above are often too time-consuming and inefficient to secure a sufficient and regular water supply, or even to obtain a full day's worth. To improve efficiency, it may be necessary to modify the cooking equipment—for example, by diverting the steam through a hose or a metal coil that is either placed directly in raw water (replaced regularly) or splashed with raw water (continuously). The method of distillation with active cooling is definitively more efficient and limited mainly by the amount of available fuel (wood, gasoline, cooking gas).

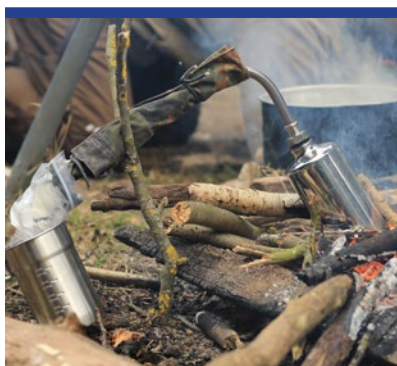
With distillation generally, it is essential to ensure that the end of the hose does not touch the water in the collecting vessel. Should the distillation vessel cool down—for example, because the fire has gone out or because the pan got splashed when wetting the cooling hose, the air pressure in the vessel changes abruptly and instantly sucks the distilled water back through the hose into the raw water. Because of the water resistance in the hose, the entire still could implode, with the extremely hot water likely to cause an injury.

Inefficient heating methods—such as burner flames that are too large or firepits that are off-center—can lead to a fuel consumption multiple times higher than the values given here.

Given that a kilogram of evaporated water emits 2,088 kilojoules when cooling down, the cooling setup of the distillation process must be chilled with at least 6.5 liters (1.5 gallons) of cold water for the temperatures in the cooler to remain under 212°F (100°C) and for the steam to condense at all. In practice that means that the cooling water has to be continually replaced.

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Distillation on a fire: The material moistened with water cools the steam but must be kept wet at all times. The plastic bag over the collecting vessel prevents the recontamination of the distillate with cooling water.



This method of distillation, based on heating water and cooling steam, is a different treatment method than sandpit distillation, where the condensation is a result of the air being oversaturated with water vapor.

## Improvised distillation methods

Distillation methods that do without monitored active cooling, or that draw the energy necessary for evaporation from alternative sources such as sunlight, are generally less efficient.

With these methods, it is very difficult to predict exactly how much drinking water can be produced and how long the distillation process takes, as they very much depend—in contrast to active cooling—on external circumstances such as available sunlight, humidity, and temperature. The values presented here must therefore be read as very *vague* reference points.

Yet these methods offer the opportunity to produce essential water in an emergency, even if they are undoubtedly unsuitable for creating large reserves.

### *Passively cooled distillation*



One improvised method with relatively small yield is the purely passively cooled still, also called “the urinator” by some authors. With this method, raw water is heated in an aluminum drinking bottle or similar container and then channeled through a hose placed in the shade.

There are very few reasons for not actively cooling the hose unless there is no other liquid available

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A distillation system made out of a Borde stove. Instead of leaving the hose to be cooled passively only by the air, it should also be cooled actively—at the very least, with mud or wet towels.



(such as when distilling your own urine in the desert). With a properly sealed container, a leakproof hose doesn't have to be positioned in a particular direction. You can lay it coiled up in a puddle of raw water and then place the other end up into the collection vessel. Boiling the water creates sufficient pressure to force the condensed distillate out of the hose.

**Note:** If you are planning on taking a piece of tubing with you for distillation purposes, please don't get one from a fish tank supplier. These PVC tubes contain large amounts of toxic plasticizers that are released when they become warm. The material has a usage temperature of 120°F to 140°F (50°C to 60°C), but distillation temperatures are significantly higher than that. Experiments with various fish tank hoses have not only generated horrid-tasting distillate but have also shown the tubes to deteriorate in the vicinity of the distilling vessel, which led to slimy tubing residue in the condensed water. Suitable tubing made from heat-resistant and harmless silicone or PTFE (Teflon) are available for a few dollars from specialist laboratory or installation traders.

### *Cane or bamboo still*



In many regions of varying climates, cane and bamboo dominate the vegetation along the banks of fresh and brackish bodies of water and even some beaches by the sea. In moderate climates, we tend to find mostly thin-stemmed subspecies, while subtropical regions are home to canes with a diameter of between 3 to 4 centimeters (1 to 1.5 inches) near the ground. In addition, bamboo is commonly found in the tropics, too.

In practice, any nontoxic plant with a hollow stem can be used to create a distillation apparatus.

Large-bore tubes can simply be cut into small sections that can be firmly sealed with wooden plugs at both ends. You may have to pierce through any potential internal walls, which is easily done with a small stick heated until glowing in





A simple still can be built with large-bore plant segments. To cool the steam, the water vapor is channeled through a small plant tube or, like here, though a tent pole.

a fire. Just below the top plug, cut as circular a hole as possible and insert a long, thin tube.

This vessel can now be filled with a little salt water and—important—a *few small stones, or a little sand*. When suspended over a fire, the water in the apparatus vaporizes and is forced through the thin tube. Some of the water condenses in the process and emerges in drops as a drinkable liquid. The stones in the still prevent superheating, or boiling delay, where some of the water suddenly starts boiling and forces the water explosively out of the vessel, causing not only a recontamination of the distilled water but also possibly severe scalding.

Actively cooling the small exit tube increases the efficiency of the method, but the yield from this method is usually only a few shot glasses full of drinking water per procedure.

Note that freshly cut, green tubes will lose their shape when drying (for example when being carried around for several days), and that a specially made plug may no longer be a tight fit.

The process is slightly different for small-bore cane: Tie together a battery of several hundred cane segments (open at the top, closed at the bottom by an internal wall) and dip it into salt water. Swipe over the top with the palm of your hand a few times to release any trapped air bubbles from the openings. The small tubes will now start to fill with water. Here, too, it is important to add a little sand.

When the bundle is heated slowly, the water in and between the cane sticks evaporates and can be collected with a piece of cloth placed over the tubes.

Once the cloth has achieved a certain basic dampness, larger amounts of water start condensing in it. The method therefore relies on a few minutes' lead time and possibly a refill with raw water.

After wringing out, the piece of cloth should be allowed to cool down before placing it back over the bundle.

By the way, it is perfectly normal for condensate produced with this method to taste *a little* salty, as contact with the tubes and water boiling over in the tubes can lead to recontamination.

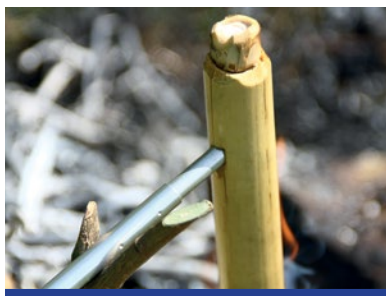
This is why this type of distillation is considered a reliable treatment method *only* for the desalination of sea water, but *not* for heavily contaminated (industrial) wastewater.

The vessels created for distillation with cane may also come in handy for transporting water.

### Bottle cascade



In my first book, published in Germany in 2006, *Das Handbuch der tierischen Notnahrung* ("The Animal Emergency Food Handbook"), I argued that the omnipresent plastic (PET) bottle may as well be considered a global natural resource. Not only has my theory since then been validated, but the waste situation has in fact become worse. While some countries encourage proper recycling by demanding



Containers channeling the steam toward a cooling device must be connected with an airtight seal. The temperature must be raised slowly to prevent the plug from being fired out of the top.

In the absence of a cooling device, or where none can be connected to the vessel, a cloth placed over the opening can catch the steam instead.



a refundable deposit for single-use plastic bottles, in many others disposable PET bottles are predestined to spend their afterlife in roadside ditches, rivers, and—decades later—as microplastic in the sea.

I have *always* and everywhere been able to get hold of such a bottle with very little effort, even on deserted summits in the Andes, in the Australian outback, and in the jungle. That's why we can consider it a readily available resource for drinking water purification (see "SODIS," page 164, and "Boiling," page 157).

PET is food-safe and can be used more or less without hesitation for distillation. (Note that depending on the place of manufacture, some possibly harmful substances such as acetaldehyde may be released into the water when the bottles are heated, but the dangers are far outweighed by the risk of dying of thirst.)

PET bottles are manufactured from a plastic preform that is heated and pressed into a casting mold. This means that when it is reheated, the bottle shrinks back to its original shape, which makes it unsuitable for prolonged use over a fire. Nonetheless, the bottles can be used, just like condoms, plastic bags, and such, for heating, boiling, and distilling several liters of water.

Besides the classic distilling methods, using a hose or cooling coil, a passively cooled yet fairly efficient method can be created by setting up a cascade of bottles: Stack the bottles on top of each other by inserting the opening of one



Almost modern art: As many open bottles as possible are slotted together via small holes in the side. The bottommost bottle is filled with salt or raw water and heated slowly. The taller the construction, the more efficient it is.

bottle circa ten centimeters (four inches) above the bottom of the next one. When the water is (carefully) heated in the bottle at the bottom, the steam condenses in the following one until the air in it gets too warm and condensation starts to form inside the next bottle. Once enough water has collected in the bottle bottoms, carefully remove the whole apparatus from the heat source, cool it down, and detach the raw water bottle. To empty, simply turn the bottle cascade upside down.

The melting point of PET is around 480°F (250°C), but the steam in this type of distillation is hot enough to deform the bottles into interesting shapes and produce white patches. They are neither harmful nor do they indicate that the plastic is beginning to melt; instead, at 280°F (140°C) the plastic transforms from an amorphous state (undirected, like glass) to a crystalline state (regular, like ice crystals), which makes it cloudy.

### *Sandpit distillation*



Sandpit distillation is a classic desalination and purification method for drinking water. However, it isn't exactly true distillation, in which water vaporizes when boiled and recondenses after cooling. The method is a miracle of water collection and purification, as it produces condensate even from seemingly dry sand.

The principle is actually very simple: A round and ideally wide pit is dug in the ground, and a container placed in the center with—if available—a hose for sucking the water through. Cover the hole with an ideally transparent plastic sheet. Fold the edges of the sheet over and tuck them into the sand, ensuring that the entire pit is enclosed with an airtight seal. Place a stone at the center of the sheet, immediately above the container.

Direct sunlight and the greenhouse effect (the “real” one, not the global phenomenon) cause the air inside the pit to become very warm. The temperature does not need to reach the boiling point of water; the warmth enables the evaporation of individual water molecules from the damp ground, slowly but surely saturating the air under the sheet. As

you have learned about the dew point, the nearer the relative humidity is to 100 percent, the smaller the difference between air temperature and a condensation surface needs to be. Higher temperatures also enable more water to be held in the air until it becomes saturated.

Temperatures inside the pit can easily reach 175 to 215°F (80 to 100°C), while the usual ambient temperature even in the summer rarely exceeds 95°F (35°C). These temperature differences are enough to condense relatively large amounts of water (for such a small space) on the plastic sheet. The individual droplets gather on the underside of the sheet and run to its lowest point, created by the stone, where they drip into the container underneath. As the effect in the pit is largely evaporation rather than vaporization, the collected water remains in the container.

Where salt or wastewater is available (the same caution regarding volatile toxins applies here, too), this can be poured onto the ground around the pit, or where supply is limited, into the pit before covering it up. In the absence of any liquid at all, cut-up plant parts can be placed into the pit.

This is more efficient than plant transpiration, especially in hot regions where the plants are likely to be xeromorphic. In this case the green plant parts must be bent, broken, or cut up before placing them into the pit, to enable the liquid to escape more easily.



Sandpit distillation enables the collection of residual moisture from the sand. Where raw water is available, this can be poured into or around the pit. Even desert plants lose their liquid in high temperatures when cut into small pieces. This makes sandpit distillation a method for obtaining and treating water at the same time.

Given the enormous amount of energy required for water to evaporate or vaporize, the efficiency of the sandpit distillation method is limited first and foremost by the available sunlight. The decisive factor is not the volume of the pit but the area covered with the plastic sheet. The



An alternative to the sandpit: Steam generated with hot stones condenses on a foil placed over a frame. The distilled water collects inside the folded-over edges of the foil.

amount of distillate produced depends on the angle of the sun, ambient temperature, and moisture content of the soil. Tested under real conditions in southern Europe, a sandpit with an area of two square meters moistened with raw water yielded around a hundred milliliters (3.4 ounces) of drinking water per hour.

## Small water supply systems

When organizing the water supply for trips with large groups, tent camps, emergency situations, vacationing in cabins, or living in remote regions, it may be worth familiarizing yourself with the construction of small, or home, water supply systems. In contrast to many improvised treatment systems or backpacking filters, these are designed to produce several hundred liters of drinking water a day.

When joining self-contained systems such as emergency storage units to the system, it is advisable to set up a two- to three-stage low-pressure system based on candle filters, which should be sufficient for ten to fifteen people depending on the drop height. If the filter system is to be fitted in remote villages or disaster areas and required to serve large groups of people, improvised stationary systems made from PVC pipes can be used.



## Home water supply systems

A whole range of filter systems are commercially available as “whole house filtration systems”—and I don’t mean the transparent jugs with little filter cartridges designed to improve the taste of your tea or coffee (they’re not really filters, anyway, but usually mere ion exchangers), but rather filtration systems designed to turn harvested rain or pump water into drinking water.

The main problem with these systems is that they are designed to work with relatively high pressure and require disposable filters that become saturated and clogged, which then need replacing. Ideally, the raw water to be treated with these filters has therefore been pretreated with a backwash filter or a washable sediment filter.

The finer the filter mesh, the higher the required pressure—and the faster it becomes clogged. It may take as little as 1,000 liters (250 gallons) of water contaminated with algae before the filter only lets a trickle of water through—although it will still be clean.

In order to construct an energy-self-sufficient system, you need a raised water store that can be connected to a filter casing with a hose. The higher the drop height, the greater the pressure. Two meters are just about enough for a three-stage system, while four to five meters produce enough pressure to filter three to five liters (a gallon or so) per minute. In principle, you could use a simple garden hose, but it is heavy and easily damaged.



For systems that need to be portable, a plastic hose for agricultural purposes has proven to be an ideal choice.

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Fittings, connectors, and couplings for agricultural watering systems can be used to build low-pressure systems. They are cheap and easy to procure.

Remember to install a stopcock at the storage tank outlet to allow the system to be drained during periods of frost, for cleaning, or for changing the filters.

### Filter housing

Given that the pressure rises by 1 bar (14.5 psi) with each ten meters of rise, it is rarely possible to build up the required standard pressure inside a gravity-based filtration system. The larger the filter area, the more water passes through, so large filter casings for ten-inch filters are more suitable than small ones.

Naturally, your choice also depends on the available space and/or transport capacity. Two filter phases after another are generally sufficient, but three are better.



For smaller groups, and for purifying rain or river water, commercially available filters for whole house filtration system are a good choice. They are relatively large and heavy, but they are reliable and—when used regularly—as good as maintenance-free.

### Filtration stages

Raw water from the storage tank is channeled through a sediment or wound filter with a pore width of between 50 and 100 micrometers. Larger particles, amoeba, and algae are trapped in the filter layers where they die and decompose over time. From there the water is channeled through a filter cartridge with as fine a mesh as possible.

The smallest pore diameters available for these types of filtration systems are in the region of 0.2 to 10 micrometers. It is worth testing to ensure that the throughflow volume is still sufficient at the smallest pore width. Even 5-micrometer pores filter out many disease-causing pathogens, and for raw



water that is essentially rain water stored in sealed cisterns or tanks, even larger pores are sufficient to filter out amoeba and similar protozoa, as contamination with significant levels of feces or bacterial germs is unlikely.

In case there are bacteria present in the raw water after all, they can be retained or reduced with a charcoal filter installed as a third stage. Such a filter will also remove waste products of decomposing microorganisms from the previous filter stages as well as any residual preservatives and disinfectants from the tank and other harmful substances from the raw water.

The filters must be replaced according to the manufacturer's instructions; if unused for several days, they and their housings should be chemically disinfected with a suitable product and drained and stored in a dry place or treated with a preservative.

### Pressure system

In order to achieve filtration with a sufficiently fast through-flow rate in the absence of adequate pressure, it may be necessary to connect a simple pump between the water tank and the filtration system. Energy-self-sufficient systems are particularly valuable in this case.

Several pumping systems from the world of camping are available for this purpose, but they don't always handle the counterpressure very well, which can be quite high in some cases. Drill pumps, based on the same principle as a gear pump and capable of producing relatively high pressures, have proven to be particularly well suited for filtration.

To be able to operate these pumps by hand, they must be fitted with a crank. Depending on the model and operation, between half a liter and five liters of water can be forced



Filter candles are exposed to raw water on the outside. Pressure forces the water through to the inside, which is then channeled to the top. Care must be taken when inserting the cartridge to ensure a poor seal does not allow water to bypass the filter.

through the filter per minute. It is not advisable to use the pump to suck water back through the filter; ill-fitted hoses can allow air pockets to form, which can reduce the negative pressure to a minimum, requiring in turn long periods of fast and “empty” cranking, which does nothing to extend the life span of the pump.



Drill pumps driven by a crank are a small and simple solution to create pressure, or when the filter needs to be backwashed.

## Stationary systems

Installing stationary systems with high throughflow rates makes sense provided they are light and flexible, and they can be assembled on-site and work for long periods of time without having to be maintained or their filters replaced every few hundred liters. There are many scenarios where improvised filter groupings come in useful. The essential prerequisite is that the raw water must be assessed accurately.

Suitable filter casings include PVC drainpipes (which are not officially approved as food-safe but available globally and currently in use for the supply of drinking water) as well as connectors, diverters, bends, siphons, and so on. They are lightweight and durable, meaning they can be installed and assembled in a variety of locations. Using several treatment methods such as oxygen precipitation, sedimentation, and

decanting, percolation devices (such as a narrow filling funnel connected to a 32-millimeter



Drain pipes, various couplings, angles, splitters, and caps as well as simple pumps and plastic tubing are the basic mobile components of a stationary system that can be transported over long distances and filled on-site.

tube fitted with a sieve at the top) can be installed with a resting section (increase the diameter to 160 millimeters), filled with gravel, and fitted with a splitter piece as a siphon on the side.

In areas with particularly high pollution levels, a filter step can be added for a chemical pretreatment with iodine, which is then separated in a downspout filled with charcoal following the germ count reduction stage. Alternatively, chemical pollutants can be partly removed with ion exchange granules.

It is a good idea to prepare a few separation inserts with various diameters cut from common household sponge cloths. The system can be stabilized by attaching it to the wall of a house or a tree trunk with holding clamps or fence wire.

The filtration system can be planned, combined, and tested before transporting it—empty—to the desired location for final assembly.

Since the individual filter stages depend on the quality—i.e., pollution levels—of the raw water, we will focus our attention here on the germ count reduction stage as the heart of all stationary systems.

It is centered around a tall pipe (as tall as possible—for example, two sections of one meter each) with a large diameter. The outlet at the bottom consists of a small diverter filled with several separator inserts before assembly. This diverter should be easy to remove in order to allow the filter to be cleaned by backwashing. The bottom quarter is filled with a mixture of fine sand and clay. This is topped with a separator and one meter or so of fine sand, which in turn is topped with another separator and twenty centimeters (eight inches) of gravel and a few larger stones to prevent the layers from being disturbed. Place another diverter at the top of the filter system and close it with a cap (for now).

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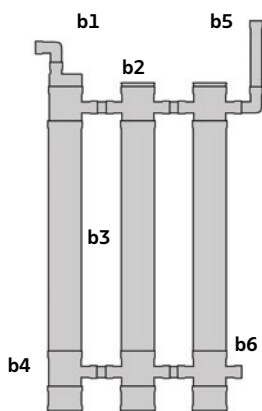
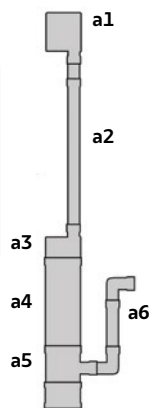
Stationary filters can be filled with a variety of filter media such as ion exchange granules.



## Examples of different stationary filtration systems

### Ventilator:

- a1 Collection funnel
- a2 Downspout with multiple drill holes for ventilation
- a3 Expanded pipe, resting, or sedimentation section
- a4 Separation stage filled with gravel or sponge cloths
- a5 Diverter above a bottom sump piece to collect residual sediment
- a6 Raised water withdrawal point, which reduces the throughflow rate

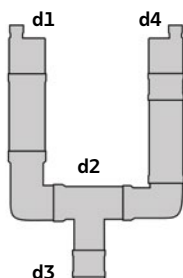
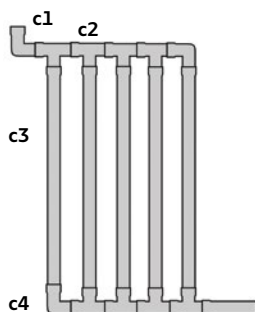


### Buffer storage:

- b1 Water inlet
- b2 Twin diverters to vent the system
- b3 Parallel pipes of large diameter
- b4 Diverters/twin diverters leading to water outlet
- b5 Vent stuffed with a sponge cloth for depressurization
- b6 Water outlet

### Parallel filtration stages:

- c1 Water inlet with long inlet pipe to increase pressure
- c2 Diverters for parallel water supply of the:
- c3 Filter pipes with ion exchanger, activated charcoal, mud/clay, etc.
- c4 Clean water outlet



### Siphon:

- d1 Inlet for water with sediment through expanded pipes
- d2 Twin diverter with a long downspout as a sump
- d3 Cap for cleaning access and to remove collected sediment
- d4 Outlet for the sedimented water

Cleaning a germ count reduction stage: When in use (left), raw water enters the system at the top, seeps through a tall and wide downspout filled with gravel and sand, and subsequently exits at the bottom. Cleaning with backwash (right): An ideally long and thin pipe is filled with water, which is then forced from the bottom to the top of the main pipe where it exits the system to the side.



Before initial operation, run water through the filtration stage for around half an hour. After adding a little suspended earth at the water inlet at the top, the water exiting at the bottom should still come out crystal clear. The filter can now be fitted with the relevant pre- and postfilters and can be operated until the throughflow is no longer satisfactory (the media of the other filtration stages such as charcoal or ion exchangers may need to be replaced sooner).

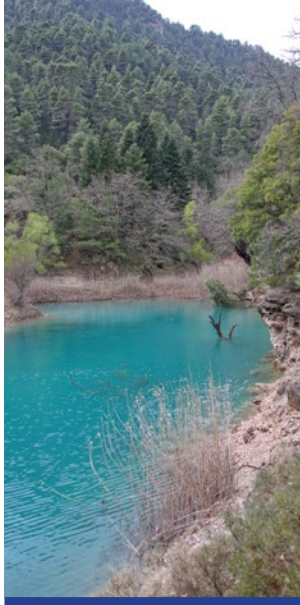
When that is the case, open the top and bottom diverters. Using an appropriate bend piece, attach a thinner pipe parallel to the sand filter that must reach to at least one meter above the top diverter. Keep filling this pipe with the cleanest water available until the backwash exiting at the top diverter is no longer cloudy. The filter can then be put to use again.

After several days of not using the filter, it should be run through with a concentrated disinfectant solution.

## Stationary UV radiation

Where there is access to a power supply, the system can additionally be furnished with a small UVC stage. Some come equipped with a special fluorescent lamp and are therefore capable of running on transformers fed by twelve-volt batteries. These “UV purifiers” are available with a minimum power of ten watts, which is easily enough to disinfect several liters of prefiltered water per minute. Ideally such a device is connected with a tap at the exit point of the system, and the flow regulated to prevent it from running through too fast. By combining

Filtering water from a clear mountain lake like this one reduces its quality. Even though the lake is undoubtedly a standing body of water, all the indicators point to the fact that it is safe to drink untreated. You should not try to purify water like this; it would only waste time and resources. Water should only ever be treated as much as necessary.

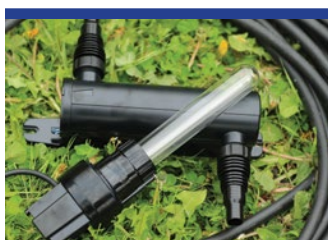


a number of different filtration stages in this way, it is possible to produce water of drinking-water quality (as per the WHO guidelines) from all kinds of raw water, even for larger groups of people.

Caution: Remember that water is a light conductor and that “hard” UVC light can cause damage to the skin and eyes. Do not let water from the tap flow directly onto skin or the face, and do not look into the water spurt. Once poured into a container, the “fleeing” light is negligible.

**Note:** A properly constructed and combined stationary filter can produce drinking water for an entire small village. It is vital, however, to assess the quality of the raw water beforehand in order to set up the appropriate purification stages.

In addition, filter media that tend to saturate must be replaced regularly.

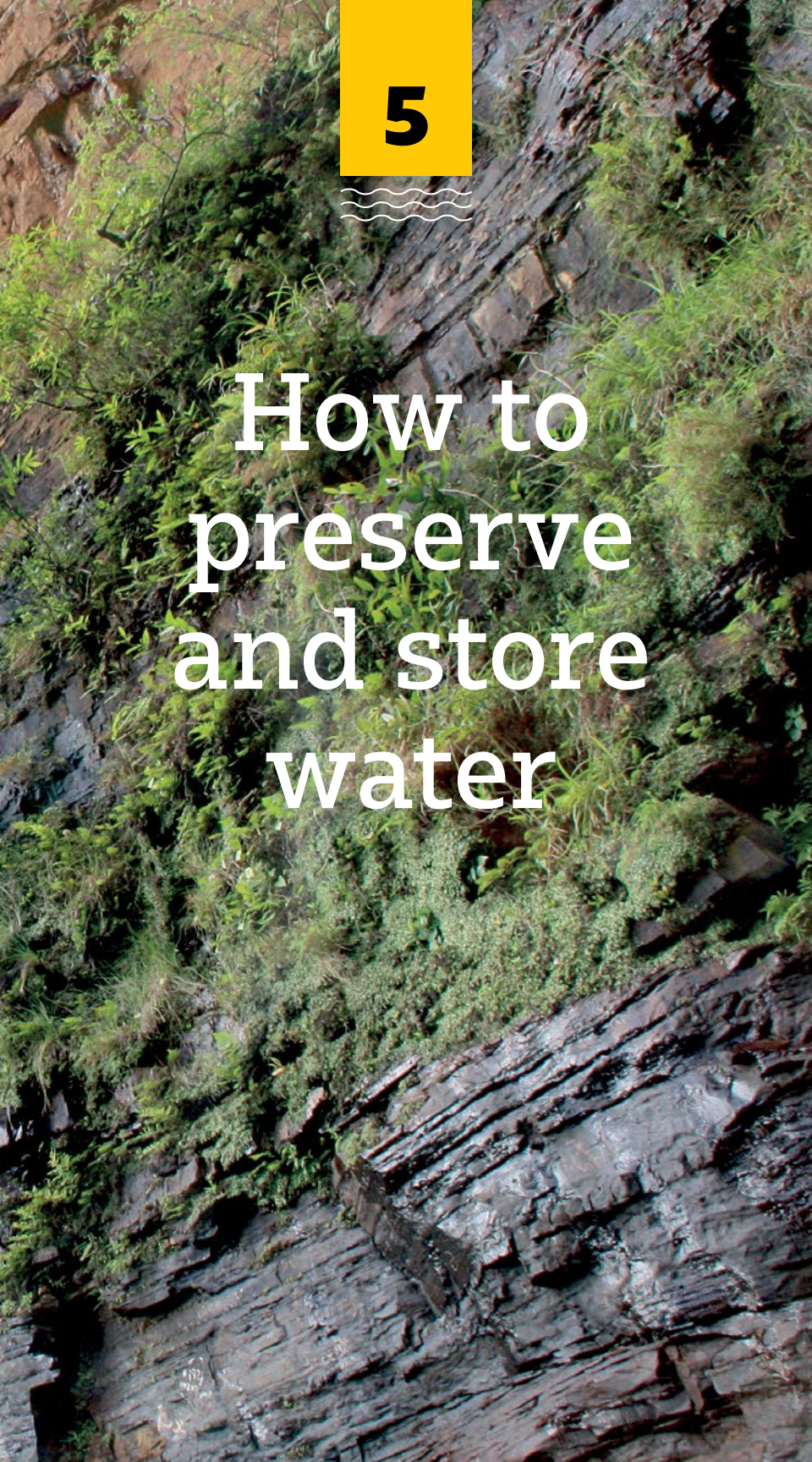


UV lamps such as this one are very effective and can disinfect several hundred liters of water per minute. Using this stage after a stationary filter makes water fit for consumption even for the ill and elderly.









5

# How to preserve and store water





# How to preserve and store water

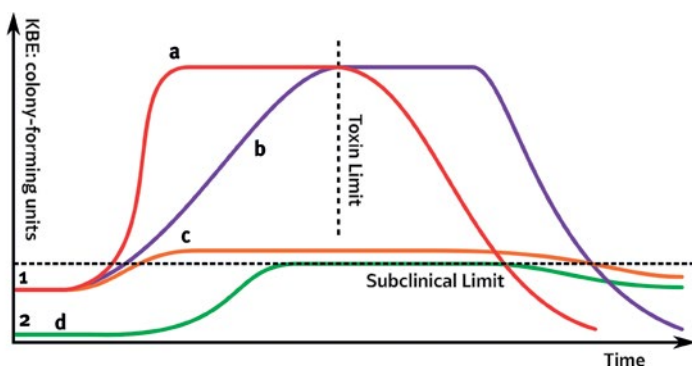
**F**rom the last few chapters, you've learned that disinfection is not the same thing as sterilization. Drinking water is generated by either killing or removing as many of the *harmful* components of raw water as possible. None of the methods explained in this book (not even the commercially available ones) result in sterile water, which is free of *any* germs or viable stages of germs (endospores, oocysts, shells, eggs). Even if we were able to produce sterile water, it would almost immediately become recontaminated when transferred to a different container with stray dried-up algae, protozoa, or spores floating in the air.

*In most cases*, the disinfecting effect of the methods described here achieves a level of purification or germ count reduction in the raw water that is sufficient to render its consumption harmless. With improvised methods, it is realistic to see a reduction in the germ count by a factor of between a hundred and ten thousand. Even sterilization conducted in a laboratory rarely eliminates germs 100 percent, instead resulting in a reduction of the germ population by a factor of one million at most, even under ideal conditions.

In the descriptions of drinking water purification methods for travelers and in emergencies, I have distanced myself from the WHO guidelines, which recommend that drinking water must be absolutely free from pathogens. Our aim is to achieve the more realistic goal of *reducing* the number of pathogens to such a level where they will not cause a disease, or that any disease they may cause passes subclinically—i.e., without any symptoms.

## Recontamination

The drinkability of water treated with improvised methods is, as you have learned, not a solid characteristic. Rather, it depends on the condition and health of the individual. It is also quite a transient state, as you can imagine. As soon as we have completed the sanitizing process, the remaining germs will continue to multiply. Under optimum growth conditions, the surviving pathogens will double in number every thirty to fifty minutes—an exponential growth. In other words, if one milliliter contained a thousand germs, half an hour later there would be two thousand, in another half hour four thousand, then eight thousand, and so on.



Growth pattern of mesophilic pathogens and their effect on drinkability with high (1) and low (2) initial germ count. With a large number of “colony-forming units,” the concentration of germs rises much more quickly above the subclinical limit (meaning a disease can break out) than with a low initial germ count. After reaching the maximum possible germ count (limited by the available nutrients), toxins start to accumulate in the solution and the germs start to die off. Above a certain level, food poisoning becomes likely. The “toxin limit” and the “subclinical limit” are both determined by the individual’s habituation and resistance to the pathogen. (a) Water with a high level of nutrients and at ideal temperatures (for germ growth) is infested very quickly (juice, nutrient solution). (b) With temperatures outside the ideal range, it takes significantly longer for the maximum germ count to be reached. (c) With low nutrient levels and high temperatures, the germs multiply quickly but don’t achieve high concentrations, barely reaching harmful levels. (d) With a low initial germ count, very low nutrient levels, and suboptimal temperatures (for example, refrigeration), the concentration of germs in the solution often won’t exceed the subclinical limit even after long storage times. These parameters define ideal conditions for long-term water storage.

Yet there is no need to drink treated water immediately or to pour it away after a couple of hours. As described in a previous chapter, practically all germs that are harmful to us in the gut are mesophilic, which means that they thrive best in an environment between 68 and 113°F (20 and 45°C). Only very few potentially pathogenic water-based germs are psychrophilic—i.e., capable of reproducing quickly in cold temperatures.

Pathogens rely on not only a suitable temperature but also certain nutrients to multiply quickly. Coliform bacteria, which can cause serious waterborne diseases, in particular require a high nutrient density in order to grow fast and exponentially in number. They have adapted to the abundance of food in the mammalian gut. In the absence of that abundant food, their growth is inhibited, and they quickly enter the “stationary phase” when their maximum population size is reached. The aim of preservation is therefore not to protect against recontamination from outside, but to prevent the *remaining viable germs* from multiplying.

When treated water is clear (i.e., free from suspended substances), has been carbon-filtered (to remove dissolved nutrients) if possible, and has been stored in the shade or other cool place, it is usually safe to drink for weeks without reaching harmful levels of pathogens.

A remaining risk is posed by bacteria that can tolerate “normal” temperatures and have only modest nutritional requirements. *Legionella* are a particularly dreaded example, as they can cause severe infectious diseases. Having said that, they don’t reach dangerous levels in a matter of days, especially if available nutrients are limited. Besides, *ingesting* legionella is deemed harmless; it is their *inhalation* that causes problems—for example, when they are hurled into the air by contaminated air-conditioning units, central ventilation systems, or public hand dryers.

The following methods have proven effective and simple to use for preserving drinking water for the medium term.

## Tyndallization

Tyndallization is the process used in laboratories to disinfect sensitive solutions by repeatedly heating the solution to boiling point and holding it at 98.6°F (37°C) (incubation). Boiling kills all relevant living germs but does not remove any nutrients from the water. The heat causes inactivate endospores to “germinate” after cooling. They transform from a resistant dormant stage into a less resilient active one and are killed when the water is boiled again. This process is repeated several times. We use this method in a slightly altered form, as the solutions used in the laboratory are generally nutrient broths or vitamin solutions for breeding bacteria, where the danger of rapid recontamination is much higher than with relatively nutrient-poor drinking water.

Water that has been heated to boiling point can be consumed immediately after cooling (see page 157) but will recontaminate quickly, as nutrients from the destroyed cells become available in the water. Reheating it briefly during the following two or three days, however, reduces the number of inactive and heat-resistant stages to vanishingly low levels. After Tyndallization, the water can be stored and consumed unchilled for several weeks.

## Repeated SODIS

After correct application of SODIS (and for a suitably long period), the water is free from viable (harmful) germs for several days. UV light is capable of killing even the stable endospores and oocysts of cryptosporidia and giardia, but if the raw water was still cloudy, or if a number of germs may have been hidden from the sunlight, for example in the lid, it is possible for a recontamination with bacteria to occur.

Exposing the water stores in suitable containers to direct sunlight for an hour or two at midday kills any new or remaining germs or endospores. After repeating the process two or three times, the water can be transported unchilled for several days or weeks, depending on its nutritional content.

This is particularly useful for prearranged desert trips where clear PET bottles can be filled with reservoir water and stored directly in the sun. As the plastic material will age and become brittle after prolonged exposure to UV radiation, stores like these should not be left to lie for more than a year. The water contained in them remains permanently drinkable, though.

## Chilling and shading

Drinking water treated with an “unreliable” germ count reduction method is particularly likely to still contain algae, which will create a fresh biomass with sunlight, nutrients, and gases dissolved in the water, leading to a “fertilization” of the water. Within a few days, this water will have a typical musty, putrid flavor. A slimy, foul-smelling and foul-tasting layer (a biofilm) forms on the inside of the container. Such water is not unfit for consumption per se, but sooner or later it will become the breeding ground for any remaining viable, infectious germs. This problem usually only arises at temperatures above 59°F (15°C).

In these situations, it is essential to counteract the algal—and hence bacterial—growth by storing the water in a cool and dark place—for example, covered with wet sand, which will chill the container through evaporation, or wrapped in a rescue blanket and placed in cold raw water. Depending on its original contamination level, raw water treated with “unreliable” methods can be stored for around two to three days.

## Silver ions and other chemical substances

In the same way that chemicals are commercially available for the disinfection of drinking water, there are also chemicals for its preservation. As mentioned in the previous chapter, agents designed for preserving water are not deemed to be reliable disinfectants. While disinfectants with oxidizing substances such as mixed oxidant solution or hypochlorite kill and destroy

pathogens, they can't prevent the regrowth of any potentially remaining germs on a permanent basis: The reactive properties of oxidizing substances imply that once they have been "activated," they don't remain stable for long.

This is why combination preparations are available that contain both a disinfectant and a preservative (often silver ions), which when dissolved in water inhibits the growth of many pathogenic species.



After disinfection, water should be stored in a cool and dark place to prevent recontamination.

**Caution:** These preservatives must be used in accordance with their prescribed application and concentrations. Attempting to disinfect very contaminated water with an overdose of a silver-based preservative or with colloidal silver carries additional risk. You are likely to not only catch an infection—as the disinfecting effect of silver ions is insufficient for badly contaminated water—but also suffer heavy metal poisoning: Prolonged consumption of silver leads to the “smurf disease” argyria, an irreversible blue-gray discoloration of the skin.

## Emergency water pouches

Seeing how today practically anything can be bought in a handy prepacked, labeled, and shrink-wrapped format, it is unsurprising to find drinking water in individual ready-to-drink portions on the market, too. These are small pouches or packets, usually filled with 4.22 ounces (125 ml) of drinking water. They are comparatively expensive: One liter can cost anything between three and ten US dollars. They are being promoted for their long shelf life and are perfectly suitable as emergency reserves to keep in the car or boat. More sensible,



stable, and equally long-lasting yet much cheaper are ordinary small water bottles (usually 330 or 500 milliliters [11.2 or 16.9 fl. oz.]), which are available in any supermarket anywhere in the world. The water in these containers is in fact sterile, otherwise it would not have such a long shelf life, so you can safely disregard any use-by date printed on them. Water that is safe to store for months is equally safe to drink after decades. The flavor may eventually become tainted by the plastic packaging, and the contents will diminish slowly due to diffusion, but that is all.

On the other hand, “normal” flavored or sugary drinks are perishable; after a while, the decomposition process begins, which will eventually render the contents unfit for consumption. Carbonated water loses its fizz over time, as the bottles are not gastight, but apart from a change in taste there should be no decline in its quality.

If you are intent on having sugary liquids available in an emergency, keep fruit or iced-tea mix powder stored in sealed jam jars or pouches, and add a little to your water as and when required.

Emergency water pouches are nothing more than tap water sealed in shrink-wrapped pouches. You can easily prepare them yourself at home by vacuum-sealing ice cubes in a plastic bag, leaving it to defrost, and then “autoclaving” it for half an hour in a pressure cooker.



## Transport and storage containers

Extreme situations often require large amounts of drinking water to be stored. Very often, drinking water or raw water is merely a transitory item, but certain situations do require appropriate supplies to be put in place. The previous chapters have already touched upon and listed different options in the context of collection and disinfection methods. To conclude, we will take a quick look into systems that allow the safe storage and transportation of water—in addition to the simple bottles and drinking systems that have been discussed already.

**Note:** It is almost impossible to calculate the exact water requirement for several days or even weeks. It may therefore be necessary to stock up on or discard some water along the way.

## Stationary storage tanks

Similar to stationary treatment systems, stationary storage tanks are an interesting option for stand-alone systems in remote camps, disaster areas, and buildings without connection to a water supply. Since these large storage tanks are usually only intended for temporary use but can be installed on a permanent basis, it makes sense to allow them to fill naturally with a rainwater-harvesting system. Due to long standing periods, the water they hold must be treated as raw water rather than fresh rainwater. This allows a large amount of water to be stored over many months and years.

While just a few decades ago, water in rural areas and in regions off the grid was still stored in cisterns, today, plastic tanks are more prevalent. Both concepts have their pros and cons. Building a cistern of stone or concrete and making it watertight is not without its problems.

Since cisterns are usually located underground, however, they are less prone to frost damage than large containers such as IBC (intermediate bulk container) tanks, which usually have a capacity of around one cubic meter (250 gallons) and are available at low cost.



Left: Cisterns and ponds should ideally be covered. Their advantage is their size: They can hold many cubic meters (several hundreds of gallons) of water. Their downside: Even water that may have been clean to begin with must now be treated as raw water. Right: IBC tanks are a good choice, especially for stand-alone systems. They are sealable and can be stacked.

Mounted on a plastic pallet and protected by a metal cage, they are mobile and stackable, but at low temperatures they are liable to freeze and burst.

A somewhat smaller intermediate solution is a heavy-duty plastic tank that can be buried in the ground below the frost line. If it does freeze, it still expands but rarely bursts. It can be filled with rainwater harvested from a small building nearby; alternatively, you can erect a simple roof of corrugated iron with guttering covered with a fine mesh to keep out insects, leaves, and moss. Larger roofs are harder to keep clean and must be checked regularly for dead animals.

For convenience, tanks like these can continuously overflow, which helps with replacing the water over time. Where these tanks are placed on the roofs of high-rise buildings as emergency backups to be fed from the supply network, their overflowing can be prevented with a float valve (similar principle to the ball cock mechanism in a toilet tank). With exposed systems such as these, it is vital to ensure they are frost-safe and to drain all pipes when it gets very cold.



A good quality downspout filter can remove insects, leaves, and moss from water harvested from a river or as rain from a roof.

## Mobile medium-size storage containers

Mobile storage containers—simply known as canisters—with a carrying capacity of between five and twenty-five liters (one and six gallons) are the most commonly used storage systems for people traveling by car or with a cart in arid regions. They also come in handy for storing locally collected or harvested water in water-deficient regions.

There are essentially two practical transportation systems: rigid plastic or metal canisters, or folding water carriers. Collapsible water containers popular with campers,

however, are best avoided. With shifting stress from prolonged use, their thin walls tend to break along the folding lines, which essentially makes them an unsuitable choice for carrying water.

Rigid water containers have the advantage of being stackable and relatively robust, but they often have one crucial flaw: Many come with an integral tap that is liable to flip open or even snap off. Some people therefore prefer jerricans such as the ones often used for fuel. Obviously, you must never use a canister that once held fuel for storing water! Food-safe canisters made from transparent material are available from every DIY store, but make sure the lid seal is of good quality.

Plastic containers have the disadvantage that they can absorb the taste and odor of adjacent canisters. In addition to labeling each canister clearly (i.e., as fuel/raw water/drinking water), it is essential to store water containers away from fuel and lubricants.

Water carriers are more easily damaged than canisters, but they have the great advantage of only taking up as much space as the water they hold. When empty, they can be transported rolled up. There are two common types available on the market: the Swiss Army water carrier with a carrying capacity of 20 liters (5.28 gallons), made from sturdy rubber and featuring a solid spout, or water bags made from much thinner material, available in various sizes and featuring a large filler cap.

The Swiss models are very reasonably priced but have one large downside: Because of their black surface, the water inside them also tends to get very hot in the sun, which unfortunately affects the taste of the water contained in them. Models made from synthetic material, like the ones made



Canisters are sturdy and easy to carry, but they take up the same space whether full or empty.

by Ortlieb, for example, impart very little flavor to their contents and are significantly lighter, but they are also more expensive and more susceptible to damage. Especially when these are carried in a backpack, care must be taken not to compress the relatively soft wide-necked cap, as that may cause it to leak. They benefit from the fact that the outlet on some water filters can be threaded directly onto this cap, preventing contamination of the drinking water through a bypass.



A lightweight water bag with a wide-necked opening (left) that connects directly to certain water filters. Unfortunately, these water bags are unreliable and easily damaged. Much better are the infamous Swiss Army water carriers (right). They can survive a drop from a height of several meters unscathed, but the water inside them quickly acquires an intense rubber flavor. Still, they are my preferred choice for desert expeditions.

## Bottles and drinking vessels

A lot has been said about bottles already. They are divided into plastic bottles, wide-necked bottles, drinking bladders, and metal bottles. Glass bottles virtually play no part in storage or transportation and, in comparison to the other models, have practically no upsides.

In my opinion, transparent PET bottles are second to none as simple drinking and storage containers when it comes to weight, price, and robustness. They do not impart

any harmful substances to their contents but are suitable for SODIS and easy to recycle. Their



Suitable collecting and drinking vessels: Transparent bottles made from PET or PC.

main disadvantage is that they are heat-sensitive and are therefore an unsuitable container for heating water or for being filled with boiling water without becoming deformed. The latter problem can be avoided with wide-mouthed polycarbonate (PC) bottles, most commonly represented by Nalgene bottles.



Metal bottles don't allow for controlled water consumption but can be heated in a campfire. Some flasks come as part of a cooking system or can be used as a distillation vessel.

Drinking bladders made from multilayered polyurethane can be filled with hot water, too, thus preventing recontamination while waiting for it to cool down.

For serious physical separation and treatment methods, however, a metal bottle will always be more suitable. Apart from coated and uncoated “Swiss hiking bottles,” there are army bottles—designed in that same alpine country—that come with an integrated stove and mug (Borde stove) but unfortunately featuring an unreliable cork cap. There are also numerous military and civilian canteens available that are suitable for boiling, distilling, and other physical water treatment methods.

Choosing the right bottle therefore depends first and foremost on the availability of water (for example, in water-deficient areas, only use transparent bottles, not drinking systems) and the treatment methods you expect to be applying (metal bottles with condensation system by the sea).

**Note:** Whether you choose metal or plastic bottles is down to personal preference. According to the current state of scientific research, neither plastic nor metal residue that may be absorbed by the water is detrimental to human health, even with prolonged use.

## Improvised transportation and storage methods

For travelers carrying nothing but a backpack—in other words, travelers with limited storage and transportation means—water bags might be a suitable option for collecting raw water or transporting drinking water in an emergency. However, water bags have their limitations, especially if unexpected rainfall should bring the opportunity to store even larger amounts of water for drier times. The experienced bushcraft survivalist should have little trouble in improvising a container from bark, reed, bamboo, or wood. The thing to remember is, however, that natural materials swell when exposed to water for a long time and crack when they dry out. Thin, lightweight plastic sheets therefore make a great travel companion for extreme and long-distance travelers, as they can be used to transport water safely on long marches.

### Storage ponds

You can even use a rescue blanket or similar sheet to build a small “pond.” Start by digging a rather shallow pit in the ground, taking care to clear all sticks and sharp stones, as the water pressure on the sheet will be quite high.

The length and width of the pit must be short enough to allow the sheet to extend well beyond the edges of the pit. Thoroughly compact the ground to prevent the soil from



Improvised vessels can be created comparatively quickly using natural materials. With a little skill, they can be fitted with a lid or—with very small capacity materials—combined into transportable batteries and even used for cooking.



giving way under the water pressure and from pulling the sheet below the surface. This pit should allow you to store between fifty and a hundred liters (fifteen and twenty-five gallons) of water.

## **Emergency containers**

An improvised storage pond is obviously more suitable for a temporary camp rather than for carrying water with you. If you have no space in the backpack for a lightweight water bag, you can buy cheap wine bladders of the sort that is normally used in wine boxes. Made from very thin plastic material, they are, however, susceptible to damage. Other alternatives are large freezer bags and condoms, which are often part of the emergency kit.

Unfortunately, these options have the disadvantage that a drop from a few inches' height or even just the swinging motion caused by walking is enough to burst the thin, pressurized skin. A simple cloth bag fashioned, for example, from a T-shirt or an unzipped trouser leg can provide stabilizing support.

Tie the piece of cloth you intend to use at one end (ideally the narrower end, unless the diameter is the same at both ends) in a tight knot, then place the—empty!—waterproof material inside. (Once filled, condoms, plastic bags, and so on will bulge at the bottom to the extent that it becomes impossible to place them inside the cloth bag without tearing them.) Start by folding over the top seam of the cloth to prevent any buttons or zips from damaging the inner bag. Then fold the top edge of the inner bag over the top edge of the outer bag so that the whole contraption can be held open with two hands. Now fill the improvised carrier with water while ensuring that there are no air pockets between the two materials. The water pushes the two material layers against each other with so much pressure that its own weight would be enough to tear the inner skin if the bottom of the water bladder was allowed to extend (for example, with a sudden movement).

Once the bag is filled with the desired amount of water, place it on the ground and gather it in a way that leaves as little air as possible above the water in the bag, then tie the inner bag with a knot or a piece of string to allow for easy untying.

Now lift the outer bag and tie it with a piece of cord around the tie of the inner bag. With the bag stabilized like this, you can walk or run without the risk of losing any water. Yet it is best carried on the outside of the backpack or in your hands—forcing such an improvised water carrier into a backpack will sooner or later end up using the water as a short-term external cooling method (see page 59).

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When using thin material such as latex or plastic sheeting to fashion a transportable container, adding a stabilizing outer shell is essential.





# Conclusion

**T**he big problem with improvised drinking-water treatment methods is that there are no visible or immediately measurable results. Disease-causing microorganisms are invisible to the naked eye, and their presence can at best be suspected based on a number of indicators. As a result—and owing to the fact that in the past many treatment methods were unnecessarily applied to water that would have been perfectly safe to drink in the first place—a number of water purification methods have developed over the course of several survivalist and bushcraft generations that are not as effective as they're made out to be.

Another difficulty arises from the fact that the usual quality requirements of drinking water cannot be met in the field—but they don't need to be. Since the first appearance of humans—in fact, since the appearance of life itself—every single cell on this planet has depended on water. Our ancestors twenty or thirty thousand years ago did not know about SODIS or water filters. We share the same physiology with them, but we are no longer habituated to dirt and soil. Human population density has increased enormously, agriculture has intensified, and we've created vast amounts of industrial wastewater. Our lack of conditioning combined with a steady decrease in naturally occurring clean drinking-water reservoirs are forcing us to perform a balancing act.

The purpose of improvised water treatment in emergencies is not to provide an entire town or city with water for all its drinking, cleaning, and washing requirements, but to prevent death from serious diseases or dehydration. Reducing the germ count by a factor of one hundred can make the

difference between a bit of a tummy ache in the night and acute and fatal diarrhea.

The first priority is not the actual treatment but rather locating and recognizing the cleanest water possible. On my travels across various climate zones, I have often had to rely on all my knowledge and experience, and I am sometimes quite grateful that I have acquired a certain robustness over the years, which has allowed me many a time to use water from even relatively suspicious sources—especially when I assumed before setting off that clean drinking water would be available and therefore decided not to cram a water filter into my already bursting backpack.

In the field, it is next to impossible to assess the quality of drinking water accurately, even if a lack of local water treatment facilities is sometimes more than evident.

I was very lucky to receive advice from a number of experts from various institutes to evaluate the sanitizing effect of the methods described in this book. The actual assessment, however, was made in my kitchen—temporarily converted into a laboratory. Before and after treatment, water samples with varying degrees of contamination were transferred onto a bacterial-growth medium in petri dishes and the number of remaining germs counted. It was important to understand how much each method was able to reduce the total germ count.

A large number of improvised purification methods failed this test or

The “quality” of water from an oasis in Egypt—this was the kind of drinking water, untreated, that a friend and I had to fall back on during a weeklong trip across the desert.



were discarded because of their impracticability (for example, not everyone has access to moringa seeds in an emergency). Other methods often described as useless turned out to be surprisingly effective. All of them, however, must be tried out and practiced to be implemented correctly in an emergency. The effectiveness specified for each method can vary significantly depending on the diligence with which it is applied.

At the end of this book, I appeal to you again not to pack the book in your emergency kit, shrink-wrapped and in pristine condition, but to become familiar with its contents and to regard the locating, assessing, and purifying of water as a bushcraft activity that is to be mastered just like the making of fires and the setting of traps.





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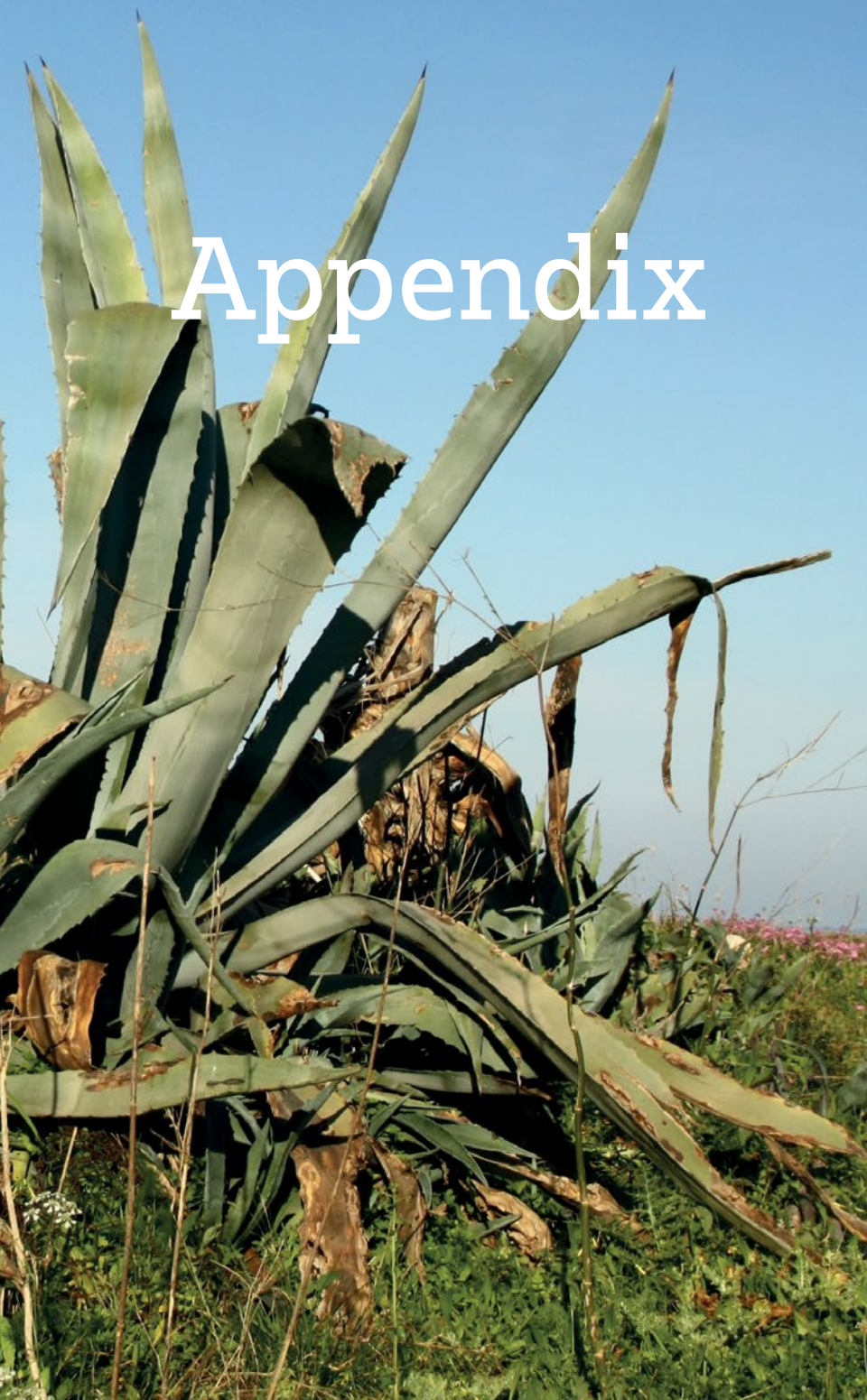
Though I have made every effort to provide information in a format that is relatively easy to follow for nonprofessional hydrologists while still being technically correct, it is in the nature of things that simplification entails a loss of precision and accuracy. I hope that my colleagues, on whose advice I depend, may forgive me for not using primary-source style citations, and for simplifying and generalizing many aspects of the subject matter.

I owe *special thanks* to those who had the daunting task to work simultaneously on my early, no doubt confusing manuscripts and to turn them into an engaging book. I would like to express my particular thanks to Susanne Fischer, at Paul Pietsch Verlage, for her patience with this seemingly never-ending project, as well as to Patricia Braun, who not only arranged the layout of the book but also supported me in the areas of photography, topic selection, and processing all these ideas.





# Appendix







# Appendix

## Drinking water and diseases

**Note:** This book is about how to find, assess, and correctly treat water to render it fit for human consumption. It does not cover the possible effects of consuming contaminated water, which is why the following information on waterborne diseases has been kept to a minimum.

As we've already seen, the attributes of drinking water depend on a whole range of factors, which means that without the benefit of laboratory equipment for its analysis it takes a certain experience to achieve an individual approximation with any degree of accuracy. And even personal experiences in the context of drinking water are often nothing more than anecdotal memories and claims:

- "Some people can safely drink untreated water from a certain source, while others get sick from it."
- "Drinking water from one river didn't cause me any health problems, while water from a similar kind of river gave me a stomachache."
- "Three weeks ago, water from a watering hole was fine to drink untreated without any consequences; yesterday, water from the same place made me ill."

All the while it remains unclear whether the illness was actually a direct consequence of drinking contaminated water. Maybe it was already developing or not even an actual illness at all; if the stomachache was caused by spoiled food, it may be connected to another mistake that may have been made, such as eating a lot of fruit immediately before drinking. You may have heard the old adage, "Don't drink water after eating fruit or you'll get a tummy ache." Nowadays, this warning is

no longer relevant, for the discomfort was caused by neither the fruit nor the water, but by yeasts and other harmless aquatic microorganisms fermenting the fruit components. In this process, large amounts of gas are produced, which in turn can cause severe stomach pains. Organic acids also formed in the process lead to diarrhea—nothing to do with waterborne diseases.

These microorganisms have nowadays vanished from tap water, which is why it is safe to eat fruit and drink water at the same time. If, however, the water is drawn from nature, treated with improvised methods, and consumed after raiding a meadow orchard, then it is as good as inevitable that a stomachache should follow. Furthermore, the pains may well be a direct consequence of the body's own bacteria reacting to the arrival of large amounts of fructose.

Nonetheless, small natural streams are commonly used to drain away *treated wastewater* from sewage works, so it is of course possible that what we assumed was a clean brook had in fact recently been contaminated with overflowing treatment products from a nearby plant following prolonged rainfall.

It is not uncommon, either, for contaminated water to be blamed for an illness when in fact the remains of last night's spaghetti Bolognese left outside the tent during a warm summer's night had doubled up as breakfast in the morning, or when the previous evening's consumption of aromatic, ethanol-enhanced drinking water around the campfire has weakened the immune system.

But regardless of what caused the outbreak of a particular illness, the advice on how to treat it remains more or less the same, so we will give a brief overview of it here.

The outbreak of a bacterial or viral disease generally means that too many germs survived their passage through acids and enzymes in the stomach and found their way into or even through the intestinal wall. Germs or parasites can attack the intestinal mucosa directly or release their toxins. The body responds with diarrhea and vomiting. In this case, you must take a break and rest. Unable to absorb any water,



the body is no longer “fit for service,” any water that is consumed just rushes through.

As a first measure, start by administering charcoal (or activated charcoal): around one gram per kilogram (half a tablespoon per ten pounds) body weight. If none is available, ingesting small amounts of clay suspended in water can bind toxins and germs and flush them out of the body.

In addition, make sure you ingest the cleanest water possible, as well as some minerals such as a little salt or ash, or, if available, small pieces of stock cube. For the first day and a half at least, avoid antidiarrheal agents. These stop toxins and harmful pathogens from being flushed out of the intestinal system, allowing more of them to be absorbed in the gut and into the bloodstream. If the diarrhea hasn't stopped by then, the situation has started to get serious, as you are at risk of exsiccosis. In the absence of any other medication or medical help, antidiarrheal medicines such as loperamide may be given after two days.

If the diarrhea is streaked with blood, mucus, or pus before then, start treatment with a broad-spectrum antibiotic according to the instructions.

Where medical treatment is within reach, a physician should be consulted after no more than three days, even without the presence of blood or pus in the stools.

In order to avoid falling ill in the first place, the following treatment options can be chosen based on the previously discussed assessment methods:

---

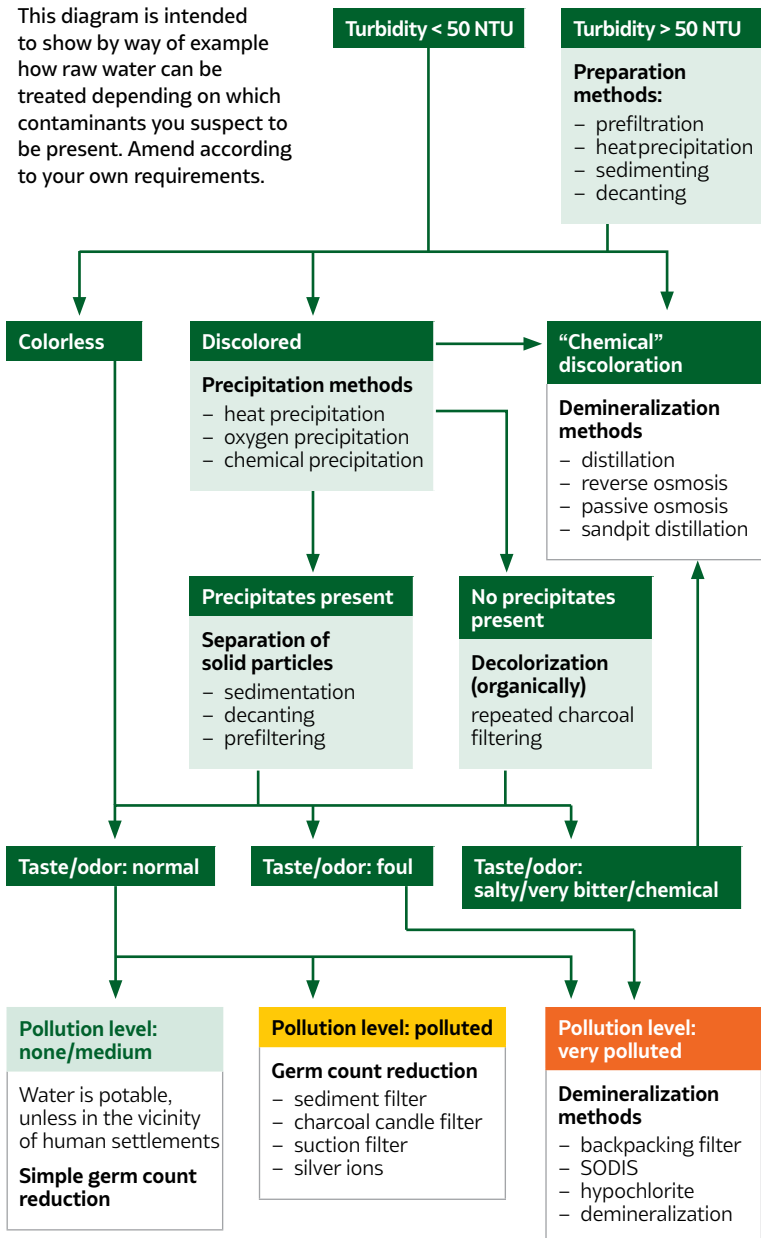
Whether water from a body of water can be consumed directly or whether it needs to be treated first depends on a number of individual factors.



# Water treatment process

Methods for treating raw water from as clean a source as possible

This diagram is intended to show by way of example how raw water can be treated depending on which contaminants you suspect to be present. Amend according to your own requirements.



# Glossary

**absorption capacity:** maximum solubility of a substance in a solution or gas

**activated charcoal stage:** charcoal filter

**adsorption:** chemical adhesion of substances to surfaces

**algae:** single-celled or multicellular aquatic organisms (plants or bacteria)

**anomaly of water:** the density of water being at its greatest at 39.2°F [4°C]

**aquifer:** underground layer of material capable of holding water

**aquiclude:** underground layer of impermeable rock

**arid climate:** no regular precipitation

**brackish water:** mixture of fresh water and salt water

**C<sub>3</sub> plants:** plants in which photosynthesis and cellular respiration occur at the same time and in the same place

**C<sub>4</sub> plants:** plants in which photosynthesis and cellular respiration occur in separate places (see xeromorphic adaptation)

**CAM plants:** plants in which photosynthesis and cellular respiration are separated in time (see xeromorphic adaptation)

**chlorine:** here, usually refers to hypochlorites or chloramines (chemical disinfectants)

**colloid:** ultrafine particles suspended or emulsified in a solution

**decanting:** careful “tipping” to pour out a liquid without disturbing sediment at the bottom of a container

**dehydration:** water-deficient stage of the body

**demineralization:** separation of all minerals and dissolved nonvolatile substances

**density:** mass per volume (metric tons per cubic meter or kilograms per liter)

**detritus:** dead organic (plant, animal, or bacterial) material on the bottom of a body of water

**distillation:** separation of liquids with different boiling points

**diuretic (agent):** substance that promotes the production of urine in the kidneys

**edema:** accumulation of water under the skin or in other parts of the body

**eurycious species:** organisms capable of tolerating a wide range of environmental factors, such as temperature, oxygen content, etc.

**eutrophic:** “overfertilized”; a body with a very high nutrient content

**evaporation:** phase transition from liquid state to vapor below boiling point; occurs only on the water surface

**exsiccosis:** internal drying out of the body following dehydration

**fecal germs:** bacteria that live in the guts of mammals and are excreted in the feces

**fluid balance, negative:** less water is available in the body (e.g., due to sweating)

**fluid balance, positive:** extra water is available in the body (e.g., after drinking)

**fluidity:** the ability to flow freely; opposite of viscosity (e.g., water is fluid, honey is viscous)

**germ count reduction:** unreliable treatment method that does not separate all present pathogens from water

**incubation period:** time span between infection and onset of an acute illness

**ion exchange:** the process of binding a charged particle to a medium while releasing another identically charged one

**iron:** metal that can indicate the presence of other heavy metals during oxygen precipitation

**kelvin:** base unit of temperature; in equations: difference in temperature

**minerals:** naturally occurring crystalline substances, sometimes soluble in water

**nonpathogenic:** does not cause a disease in a particular species

**osmolarity:** concentration of osmotically active particles, measured in osmols per liter

**osmosis:** process in which water and osmotically active particles attract each other

**osmotically active:** capable of chemically “attracting” water

**oxidizing substances:** disinfectants releasing reactive oxygen

**pathogen, facultative:** organisms capable of causing a disease under certain circumstances

**pathogen, single-celled:** infectious organism consisting of one single cell

**pathogenic, human:** causing disease in humans

**Peltier heat pumps (or element):** thermoelectric device that moves heat from one side to the other when a DC current is applied

**precipitation:** crystallizing substances in a solution

**raw water:** water collected from a source

**reliable treatment methods:** methods that remove all or as many pathogens as possible

**silica gel:** substance utilized to draw moisture

**solute:** a substance dissolved in a solution, broken down into molecules

**stenecious species:** organisms that depend on specific environmental factors in their habitat

**subarid:** arid climate with periods of rain

**subclinical:** an illness passing without any noticeable symptoms

**sublimation:** “evaporation” of ice without turning into water first

**thermal agitation:** also known as Brownian motion; particles oscillate because of their thermal energy and collide with neighboring molecules

**treatment:** purification of raw water

**unsaturated zone:** moist underground layer between ground-water level and surface

**urine, concentrated:** urine with low water content and high concentrations of bodily waste products

**vaporization:** phase transition from liquid state to vapor at boiling point; occurs in the entire body of water

**waterborne disease:** disease transferred through substances or organisms present in drinking water

**xeromorphic:** evolutionary adaption to a hot and arid environment

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# About the Author



**JOE VOGEL** is Germany's most renowned survival expert. From expeditions in the Australian outback to journeys through Africa, Central and Southern Europe, Asia, and South America, he has spent years traveling the remotest regions on Earth—accumu-

lating extensive experience and putting his survival skills to the test in the process. He teaches via his website, survival courses, videos, and books, of which this is the second to be published in English.

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